MIAMI UNIVERSITY
ARMILLA
LIBRARY

THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1908

"THE OLDEST KNOWN REPTILE."—*ISODECTES PUNCTULATUS* COPE

S. W. WILLISTON
The University of Chicago

Recently M. Thevenin has described and figured a very interesting new air-breather from the Stephanian, or uppermost Carboniferous, of France, under the name *Sauravus costei*, referring it to the Reptilia. The form, of small size, has a long body, probably a long tail, vertebrae with persistent notochord, apparently no hypocentra, single-headed ribs attached intercentrally, two sacral vertebrae, ossified carpus and tarsus, and a phalangeal formula, for the hind feet of 2, 3, 4, ?, ?. There are twenty-three or twenty-four dorsal vertebrae; the humerus shows no epicondylar foramen; the tarsus has two bones in the proximal row, a centrale and four distalia; and slender ventral ribs are present. The author's conclusions are:

> En résumé, *Sauravus costei* du Houiller de Blanzy est le plus ancien Reptile trouvé jusqu'à présent en France. Malgré son ancienneté, il est déjà très évolué, car ses membres sont à peu près aussi parfaits que ceux des Sauriens actuels, quoique la coalescence des os du tarse soit moins achevée que chez ces derniers. Il a pourtant des charactères primitifs; par ses vertèbres ensablier à notochorde continue et par ses côtes ventrales, c'est un Rhynchocéphale. Il doit, jusqu'à ce que son crâne soit connu, être provisoirement placé dans le même ordre que *Palaeohatteria, Callibrachion, Kadaliosaurus*, qui sont d'âge un peu plus récent; il est plus perfectionné que le premier de ces genres.[1]

In the *American Naturalist* for April, 1896, Professor Cope, in a discussion of the Cotylosauria, made the following statement:

[1] *Annales de paléontologie* (1907), Pt. 3, p. 19.

A single genus has been found in the Coal Measures of Ohio, which is represented by a species which I shall call *Tuditanus punctulatus*. It is of small size, and the maxillary teeth are of equal length. I can not distinguish it from *Isodectes*, which belongs to the Pariotichidae. The other species which are referred to *Tuditanus* are Stegocephalia. *This is the first identification of a true reptile in the Coal Measures.*

In the following year (*Proc. Amer. Phil. Soc.* 1897, p. 88), under the heading Isodectes punctulatus, he said:

A collection from Linton, Jefferson County, Ohio, obtained from Mr. Samuel Houston, contains the greater part of the skeleton of what I suppose is this species. The head, scapular arch and [most of the] fore limbs are lost. The remainder agrees very well with the typical specimen which was obtained by Dr. Newberry from the same locality and horizon . . . . The specimen is of importance as pertaining to the oldest known reptile, and the only one which has been, thus far, positively identified from the Coal Measures.

The paper was not published till after Cope's death, and he did not see all the proofs.

Hay, in his catalogue, for what reason I do not know, refers the species back to *Tuditanus* and the amphibia, and there has been no further reference since of any kind to the species.

Very recently, through the kindness of Secretary Walcott of the Smithsonian Institution, and Professor Dean of Columbia University, the type specimen of *Tuditanus punctulatus*, and the specimen referred to above by Professor Cope, have come under my observation. The original type of *Tuditanus punctulatus* will be shortly discussed by Mr. Moodie of this university. The specimen which Professor Cope so positively and decisively referred to the Reptilia is of great interest in view of the recent discussions as to the origin of that class of vertebrates. Because of recent discoveries connecting so intimately the Stegocephalia with the primitive reptiles, it is somewhat hazardous to say with assurance that the specimen really is that of a true reptile. Perhaps all of significance that is now left as a distinguishing characteristic of the two classes is the greater or less development of the parasphenoid, and, as the skull is wanting in this particular specimen, as it also was in the specimen referred by Thevenin to the reptilia, we must await future discoveries for the final solution of the question. It is my opinion, however, that Cope was right, and the form should be, provisionally at least, referred to the reptilia.

FIG. 1.—*Isodectes copei* Will., enlarged (plesiotype of *Tuditanus punctulatus* Cope).

I give herewith an enlarged photograph of the specimen, which will show, at a glance, the striking characteristics of the form; the figure given by Cope is in some things incorrect and obscure. In a very careful study of the specimen, I find no corrections of his rather brief description, but there are some facts that I can add with assurance. Positive indications of twenty-three dorsal vertebrae are present, and, since the left manus is doubtless in its normal position on the block, it is hardly possible that there could have been more than one or two more, that is, the number is doubtless the same as that of *Sauravus*. The ribs are small, slender, and curved, moderately dilated at the proximal extremity, but without real differentiation into head and tubercle; they are all attached intervertebrally. The vertebrae were certainly amphicoelous, and doubtless with persistent notochord, agreeing with those of *Sauravus*, and the Microsauria generally. The vertebral spines are rudimentary; and there are no indications of any kind of ventral ribs—one is safe in saying that the animal in life had none—in this respect differing from *Sauravus*. Nor is there any distinct evidence of hypocentra, though it is not impossible that such bones of small size may have been present. All the dorsal vertebrae bear ribs, and the first three of the caudal series also. Two vertebrae intervene without free ribs. On the left side the upper border of an ilium is discernible, close to the sides of the centra, and between them and the head of the femur. This ilium was certainly united to these two vertebrae. There were two sacral vertebrae, as in *Sauravus*, a reptilian character. The specimen lies on its ventral side, and the pubes and ischia, hence, are not visible. The tail, like the body, was evidently long and slender.

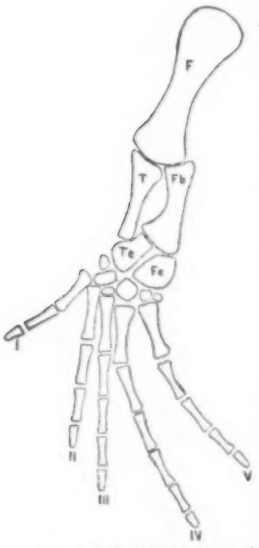


FIG. 2.—Left hind leg and foot of *Isodectes copei* Will., enlarged.

The perfection of the hind limbs is such that scarcely any thing

more could be wished for. I have no emendations to make of Cope's determinations, save to say that the phalangeal formula was certainly 2, 3, 4, 5, 4. I accept Cope's interpretation of the tarsus, as shown in the figure, with the proviso that possibly the proximal row may be composed of the three bones, tibiale, intermedium, and fibulare, but I do not think so. The bones exhibit full chondral ossification, and not perichondral alone, as is the case with the Branchiosauria, and many of the Microsauria also, probably. Whether microsaurian or reptilian in nature, the presence of such a tarsus, with its fusion of intermedium and centrale is of great interest, since *this is the oldest known tarsus and foot of an air-breather in existence*, the Linton horizon, of middle or lower Pennsylvanian being lower than others hitherto known yielding Microsaurian remains.

The imperfect left hand is the only part preserved of the fore limbs. Four metacarpals are, however, clearly shown, and two ossified carpals, together with several phalanges.

The apparent absence of ventral ribs and the possible absence of hypocentra would seem to remove our form from direct ancestral relationships with the later reptiles, but there is not a solitary character which can be discovered in the specimen that is not reptilian. That the specimen pertains to the same species, or even genus, as that represented by the type specimen of *Tuditanus punctulatus* is very doubtful, and Cope was not assured of the identity. That specimen indicates an imperfect chrondral ossification of the bones, and there are no signs of carpal bones, though the metacarpals are preserved. Until further evidence is forthcoming, the present specimen may be known as *Isodectes copei*, though the generic identity with the Permian form is very problematical.

M. Thevenin believes that his *Sauravus* is a rhynchocephalian; I cannot agree with him. In all probability the head of *Sauravus* will be found to be stegocrotaphous, of the Stegocephalian or Cotylosaurian type. If the parasphenoid is found to be considerably reduced in *Sauravus costei* and *Isodectes copei*, even though there be two occipital condyles, they must both be referred to the Reptilia; if not, they must be classified with the Microsauria. That the two forms are related one cannot doubt. But, wherever they may be finally placed, both clearly show reptilian characteristics. It is clear that the primi-

tive reptilian phalangeal formula was that now persistent in the lacertilia and *Sphenodon*, 2, 3, 4, 5, 4. In *Ceraterpeton*, a later form than *Isodectes copei*, Woodward has demonstrated the formula 2,3,4,4,3, in one species at least. The number 2,3,3,3,3, so characteristic of the mammals, is a late specialization, and can have, in my opinion, no genetic relations with the similar formula in most turtles. In other words the phalangeal formula is not of the great importance that some authors have attached to it.

The attachment of the ribs to the intercentral space is very hard to explain under the supposition that the amphibian centrum is the hypocentrum; if the vertebrae are really composed of the pleurocentra, the entire, or apparently entire, loss of the hypocentra in these the earliest known air-breathers offers another bewildering problem.

There are those who believe that the reptiles arose from two distinct groups of the amphibia, one from the Microsauria, the other from the Temnospondyli; and I must confess that *Isodectes* helps that theory materially, for its relationships with the Microsauria on the one side cannot be gainsaid. But, the close relationships between such forms as *Pariotichus*, *Procolophon*, *Telerpeton*, the Pelycosauria, the Cotylosauria, Pareiasauria, and Temnospondyli complicate matters here exceedingly, and leave the whole subject still in great obscurity.

THE ORIGIN OF AUGITE ANDESITE AND OF RELATED ULTRA-BASIC ROCKS

REGINALD A. DALY
Massachusetts Institute of Technology, Boston

CONTENTS

INTRODUCTION.
TEMPERATURES AND ORDER OF CRYSTALLIZATION IN BASALT.
SINKING OF THE PHENOCRYSTS.
FORMATION OF ULTRA-BASIC MAGMAS AND OF AN ANDESITIC MOTHER-LIQUOR.
TESTS OF THE HYPOTHESIS.
1. Chemical relations.
2. Observed cases of sunken and risen phenocrysts.
3. Andesite actually observed to have been derived from basalt at an active volcano.
4. General field relations.
5. Relation of augite andesite to other andesites.
6. The rival hypothesis of magmatic differentiation.
SUMMARY AND CONCLUSION.

INTRODUCTION

Petrographers are in general agreement as to the existence of many close mineralogical and chemical similarities between augite andesite and basalt. It has, in fact, been found to be impossible to draw any sharp line between the two species. Nevertheless, the olivine basalts, volumetrically the most important class of lavas on the globe, are distinctly characterized by the great abundance of the basic phenocrysts, augite and olivine with which basic plagioclase and much magnetite are regularly associated as minerals of early generation. The list of phenocrysts in augite andesite normally includes the pyroxene and an average plagioclase which is more acid than that in the olivine basalts; olivine is absent and magnetite is less abundant than in the basalt.

These relations suggest the hypothesis that the andesite has been differentiated from the basalt by a process of fractional crystallization. This hypothesis is, in principle, nothing new, but it seems never to have been applied in detail to this particular pair of rock-species.

Vélain's observations at the isle of Réunion led him virtually to state the hypothesis, but, at the time of the publication of his memoir, very little was known as to the actual temperatures of crystallization in lavas, as to the degrees of fluidity which the lavas exhibit at those temperatures, nor as to the density of molten lava, phenocryst, or remelted phenocryst. It was, therefore, impossible for Vélain to show the exact conditions under which fractional crystallization can produce an andesitic lava from an original basalt. The experimental studies of the last twenty years have now made it possible to discuss the process of differentiation somewhat more fully.

It is one purpose of this paper to offer a brief statement of the hypothesis as viewed in the light of the experiments of Doelter and others on the properties of lavas during crystallization. A second purpose is to lay emphasis on the enormous scale in which this particular kind of differentiation of lavas has taken place. It appears to be a world-wide phenomenon. Thirdly, the hypothesis necessarily involves the correlative derivation of certain ultra-basic lavas and rocks from olivine basalt. The conception has thus become of practical value to the writer in helping to explain the recurrent field-association of olivine basalt, augite andesite, and various peridotitic rocks discovered in the Selkirk, Columbia, and Cascade mountain-ranges of British Columbia. The hypothesis will here be presented in a general form, for, while it appears to explain the field-occurrences actually studied by the writer, the conception, like all petrogenic hypotheses, should stand the test of geological experience throughout the world.

TEMPERATURES AND ORDER OF CRYSTALLIZATION IN BASALT

As a result of numerous experiments on artificial basic melts and on natural lavas, as observed under the microscope, Doelter has proved that olivine, augite, magnetite, and plagioclase crystallize in the order which has been deduced from the microscopic study of basalt by Rosenbusch, Zirkel, and other systematic petrographers.[1]

According to Doelter, both magnetite and phenocrystic olivine crystallize from artificial basic melts at temperatures ranging between 1200° and 1030° C. The olivine largely crystallizes between 1200°

[1] C. Doelter, "Die Silikatschmelzen," *Sitzungsberichte der k. Akad. d. Wissen.*, Vienna, Math.-naturw. Klasse, Bd. 103, 1904, p. 177.

and 1135° C.; the magnetite, largely between 1195° and 1100° C. The range for phenocrystic augite is 1190–960° C., with the most abundant crystallization between 1190° and 1100° C. The range for labradorite is 1125°–1075° C. He observed augite phenocrysts developed in molten basalt at the range, 1085°–920° C.; in molten limburgite at 1150°. Magnetite formed abundantly in molten basalt at 1095° C. and in molten limburgite at various temperatures ranging from 1170° to 1065° C. For rock-melts he records only one determination for olivine which "probably" crystallized out at 1085° C. in molten basalt.

Throughout most of the period of phenocrysitc development, that is, through a fall of temperature from 1200° to about 1080° C., basaltic lava is still notably fluid. Other experiments by Doelter have shown that strong fluidity characterizes various basic lavas at the following respective temperatures:

Etna basalt	1010° C.
Remagen basalt	1060
Vesuvian lava	1080
Limburgite	1050

It is fair to conclude that at the temperature of 1050° C. the average olivine basalt is fluid, and at 1100° C. quite thinly fluid. At the latter temperature its kinetic viscosity is probably comparable to that of the Hawaiian basaltic flow which Becker has calculated to have had, at the time of its emission, a viscosity about fifty times that of water.[1]

SINKING OF THE PHENOCRYSTS

In lava of such relatively high fluidity the olivine, augite, and magnetite crystals must slowly sink. Combining the results obtained by C. Barus[2] and, more recently, by J. A. Douglas,[3] on studies of volume changes as basic rock changes from the holocrystalline state to the glassy and then to the molten condition, the present writer has calculated that olivine basalt would have, at 1100° C. and at one atmosphere of pressure, a specific gravity averaging about 2.74; its groundmass, specific gravity ranging from 2.55 to 2.60. At the

[1] G. F. Becker, *Amer. Jour. of Sci.*, Vol. III, 1897, p. 29.

[2] *Bull. No. 103.*, U. S. Geological Survey, 1893.

[3] *Quart. Jour. Geol.*, Vol. LXIII, 1907, p. 145.

same temperature crystals of olivine (3.40), augite (3.30), magnetite (5.00), labradorite (2.70), and anorthite (2.75) would have specific gravities of, respectively, about 3.30, 3.20, 4.85, 2.61 and 2.66. These values are only approximate, but they show the order of the density differences to be expected between the phenocrysts and their mother-liquor. It appears probable that all the crystals except labradorite would slowly sink in the mother-liquor.

Some idea can be obtained of the rate at which the heavier phenocrysts would sink. For a spherical body the velocity of subsidence (x) at a time when steady motion is reached in a highly viscous fluid, may be found by solving the equation:

$$x = \frac{2g}{9} \times \frac{r^2(d-d')}{v},$$

where g = the acceleration of gravity; r, the radius of the sphere; d, the density of the body; d', the density of the fluid; v = viscosity.[1] This equation has been experimentally verified by Ladenburg who found that steel spheres, ranging from about 0.075 to about 0.2 cm. in radius took, respectively, from 570 seconds to 3,858 seconds to fall through a 20-centimeter column of Venetian turpentine—a substance a hundred thousand times more viscous than water.[2]

In an experiment by Jamin, pieces of stone sank through a layer of pitch in the course of several days (quelques jours), and corks simultaneously rose through the pitch, which, at 6° C, is much over 1,000,000,000,000 times as viscous as water.[3]

It is thus clear that even if the viscosity of the lava, within the temperature interval of early phenocrystic development, be many thousand times that of water, the phenocrysts must tend to sink. So long as such a crystallizing lava-column remains in its conduit and there undergoes cooling through the temperature interval, 1200°–1050° C.—a process necessarily involving a long period of time—the settling of the magnetite, olivine, and augite crystals will continue, though at a continuously slower rate. Theoretically the settlement

[1] Cf. Poynting and Thomson, *Textbook of Physics, Properties of Matter.* (London, 1902), p. 222.

[2] R. Ladenburg, *Annalen der Physik*, Vol. XXII, 1907, p. 287.

[3] Jamin et Bouty, *Cours de Physique* (Paris, 1888), Tome 1. 2e fascicule, 1888, p. 135.

will continue during the time occupied in the drop of temperature of another 100° C. or to the point when practical rigidity is established; but the rate of settlement must then be very considerably slower than in the interval, 1200°—1050° C. During the last-mentioned interval practically all of the olivine, much of the phenocrystic augite, and much of the magnetite of early generation has settled out of the upper part of the lava-column. Below 1050° C. the mother-liquor crystallizes. New crystals of magnetite and phenocrysts of augite and feldspar are formed but, because of the greatly increased viscosity, do not sensibly sink or rise in the freezing melt.

To estimate the chemical composition of the mother-liquor it would be necessary to know the composition of the original basalt and the quantity and composition of each settled-out phenocrystic material. The problem may be solved through a careful quantitative chemical study of a typical olivine basalt; the results are of the same order as those obtained from a comparison between the average compositions of the world's olivine basalt and of its phenocrysts. The result of these comparisons will be detailed on a later page.

FORMATION OF ULTRA-BASIC MAGMAS AND OF AN ANDESITIC MOTHER-LIQUOR

As the phenocrysts sink they enter levels in the conduit where the temperature is higher than near the surface, and where the basalt is as yet completely molten. Probably the lava-column grows slightly more dense toward its base, according to faint chemical differences in the successive strata. The sunk phenocrysts, at the lower levels and higher temperatures will, in turn, become re-dissolved or melted. Deville,[1] Doelter[2] and others have shown that both olivine and augite expand extraordinarily in passing from the crystalline state to the glassy. The specific gravities of a few typical specimens at room temperatures are indicated in the following table:

	Crystal	Glass	Molten at 1200° C.
Augite (Doelter)	3.30	2.92	2.83
Augite (Deville)	3.267	2.803	2.72
Olivine (Deville)	3.381	2.831	2.75

[1] Cf. F. Zirkel, *Lehrbuch der Petrographie* (Leipzig, 2d ed., 1893), Vol. I, p. 680.

[2] C. Doelter, *Physikalisch-chemische Mineralogie* (Leipzig, 1905), p. 8.

Each of these glasses would expand, with heating, at least as fast as diabase, e.g., 3 per cent. for 1200° C. (Barus). At 1200° C., therefore, the remelted crystals would have specific gravities at least as low as the values shown in the third column. The specific gravity of normal basalt at 1200° C. for a type which is holocrystalline at specific gravity of 3.00, is about 2.74; that for a type holocrystalline at 3.10 is about 2.83—both these values being calculated from the data of Barus and Douglas. There seems to be good reason to believe, therefore, that the remelted and more or less perfectly dissolved phenocrysts would not sink indefinitely deep in the lava column, but would come to rest, forming one or more ultra-basic layers in the conduit.

In an active volcano the time allowed for the growth and sinking of phenocrysts may be long enough for a complete differentiation, or it may suffice only to remove some of the olivine and magnetite from the cooling surface layer of the column, or it may be so short as to forbid the growth of phenocrysts in the vent. Eruption will necessarily arrest or greatly retard the process. Where the outflow is rapid and continuous the original olivine basalt appears at the earth's surface. There, of course, the rapid cooling generally prevents recognizable differentiation in the way possible, and, apparently necessary, in the vent itself when the basalt stands within it for a considerable time.

We have, then, to expect in nature a continuously graded series of lavas from pure olivine basalt, through olivine-free basalt, to those phases of the mother-liquor which must approximate a basic augite andesite and then an acid augite andesite. The last rock would thus represent the one phase, the more voluminous phase, of this kind of differentiation. In view of the notably uniform composition of olivine basalts throughout the world we must further expect, that, in all cases where the fractional crystallization has run a complete course, the more acid phase should be relatively uniform in chemical composition. Its phenocrysts form when the magma's viscosity is relatively high and sinking is very slow.

The other products of the differentiation must also show a very great variation in composition. According to the special thermal conditions and shape of each lava-column, the phenocrysts must sink

to different depths, and be segregated or dissolved in highly different proportions in different levels of the lava-column. From the original olivine basalt many types of ultra-basic basaltic magma and of peridotitic magma might be developed in the same conduit. During energetic eruption or intrusion into the walls of the conduit these might become mixed with each other and the resulting rocks present just such great variation as is actually observed in the peridotite family. Many peridotites, the picrites, limburgites (magma basalts), and abnormally olivinitic basalts are, in this view, the rocks derived from the fractional crystallization of olivine basalt, while augite andesite represents the other pole of the differentiation.

TESTS OF THE HYPOTHESIS

1. *Chemical relations.*—The view that olivine basalt may be the parent of augite andesite and of several ultra-basic igneous types is well supported by a comparison of Streng's total analysis of a dolerite and his analysis of its own glassy base.[1] The two are here quoted.

	Dolerite	Glassy base
SO_2	49.08	55.15
TiO_2	1.82	2.05
Al_2O_3	13.43	15.37
Fe_2O_3	6.49	4.66
FeO	5.92	5.73
MgO	9.58	4.20
CaO	8.92	7.62
Na_2O	3.42	3.45
K_2O	1.00	0.74
H_2O	0.32	0.80
P_2O_5	0.51	
	100.49	99.77

The phenocrysts of the dolerite include andesine, augite, enstatite, and olivine; and magnetite is, of course, a noteworthy constituent. The composition of the glassy base clearly tends toward that of an augite andesite, though the whole possible amount of phenocrystic development was, in the case of this dolerite, not attained. Streng observed that the phenocrysts were largely or altogether wanting in the upper-surface layer of the dolerite flow, but he thought it "improbable" that their absence was due to settlement of the crystals. He attributed the phenomenon rather to the operation of Soret's principle,

[1] *Neues Jahr. für Min., etc.*, 1888(2), p. 211.

the flow having undergone true magmatic splitting under the influence of a maximum rate of cooling at the surface. As a result of the magmatic differentiation the lava crystallized differently near the surface and within the main body of the flow. To petrologists of the present day this view must seem highly improbable, as it involves an impossible speed of molecular diffusion. The alternative view, rejected by Streng, that the andesitic, phenocryst-free surface phase is due to settlement of the olivine and pyroxene, certainly seems more worthy of belief.

Secondly, the hypothesis of fractional crystallization might be tested by a comparison of the analyses of the world's average olivine basalt, augite andesite, and ultra-basic rocks, along with the average analysis of each of the staple phenocrysts in olivine basalt. An approximation to most of these averages has been made possible through Osann's great compilation of the rock-analyses made between the years 1884 and 1900.[1] From his tables an average of all the available typical analyses for each rock-species has been calculated by the present writer.

In Table I, Column 1, the average composition of 161 typical basalts (largely olivine-bearing), is entered. In Columns 2 to 6 are entered, in order, the average compositions of 11 Hawaiian basalts, 17 olivine diabases, 9 dolerites, 11 melaphyres, and 17 olivine gabbros. In Column 7 is entered the average of the 198 analyses which include all but the olivine gabbros. Since some of the basalts are olivine-free (perhaps through settling out of the phenocryst) it seems probable that the addition of the 17 olivine gabbro analyses to the average total would render it more nearly representative of the true world-average than that shown in Column 7.

Column 8 of Table II indicates the result of averaging all 215 analyses given in partial averages in Columns 1, 3, 4, 5 and 6, Table I, and hence represents rather closely the mean composition of olivine basalt throughout the world.

Column 9 gives the result of averaging 33 of the most typical augite andesites in Osann's compilation. Columns 10, 11, and 12 give the similar averages of, respectively, 49 peridotites, 7 limburgites and 3 picrites.

[1] A. Osann, *Beiträge zur chemischen Petrographie*, Part 2, Stuttgart, 1905.

TABLE I

AVERAGE ANALYSES—BASALTS AND ALLIED ROCKS

	1 All Basalt	2 Hawaiian Basalt	3 Olivine Diabase	4 Dolerite	5 Melaphyre	6 Olivine Gabbro	7 First General Average
SiO_2	48.78	48.36	50.10	49.50	50.60	46.49	49.06
TiO_2	1.39	0.66	1.25	1.42	0.68	1.17	1.36
Al_2O_3	15.85	15.40	14.43	14.37	17.40	17.73	15.70
Fe_2O_3	5.37	6.48	5.06	6.55	4.57	3.66	5.38
FeO	6.34	10.07	6.31	5.84	6.29	6.17	6.37
MnO	0.29	0.80	0.25	0.17	0.46	0.17	0.31
MgO	6.03	4.19	7.32	7.75	4.89	8.86	6.17
CaO	8.91	8.69	9.53	9.96	8.09	11.48	8.95
Na_2O	3.18	3.34	2.75	2.50	3.23	2.16	3.11
K_2O	1.63	1.30	0.73	0.84	1.76	0.78	1.52
H_2O below 110° C	0.73	0.43	2.00	0.29	1.83	0.18	1.62
H_2O above 110° C	1.03			0.37		0.86	
P_2O_5	0.47	0.28	0.27	0.44	0.20	0.29	0.45
No. of analyses	161	11	17	9	11	17	198

Sum, 100.00 in each case.

Sum, 100.00 in all analyses.

TABLE II

AVERAGE AUGITE ANDESITE, OLIVINE BASALT, PERIDOTITE, LIMBURGITE AND PICRITE

	8 Second General Average Olivine Basalt	9 Augite Andesite	10 Peridotite	11 Limburgite	12 Picrite
SiO_2	48.84	57.50	44.39	41.69	43.24
TiO_2	1.35	0.79	0.88	0.67	.....
Al_2O_3	15.90	17.33	5.14	14.80	15.19
Fe_2O_3	5.23	3.78	3.88	15.04	8.62
FeO	6.30	3.62	6.70		7.89
MnO	.29	0.22	0.19	.....	.....
MgO	6.38	2.86	29.17	8.64	8.56
CaO	9.15	5.83	6.31	11.98	13.78
Na_2O	3.05	3.53	0.64	3.52	0.54
K_2O	1.46	2.36	0.76	1.17	0.48
H_2O	1.60	1.88	1.80	2.36	1.21
P_2O_5	0.45	0.30	0.14	0.13	0.49
No. of analyses	215	33	49	7	3

Sum, 100.00 in each case.

All of these averages were made after the method of Washington and Clarke in their latest determinations of the average rock-analysis for the world. Thus, the average for each oxide is based only on the

actual number of its determinations in the respective group; "trace" is taken to mean 0.01 per cent.

For the purpose of making a fair comparison among these averages it is necessary to recalculate them all as anhydrous; for, clearly, a large, though unknown, fraction of the water entered in the hundreds of analyses, must be regarded as mechanically absorbed water.

Table III, Columns 13, 14, 15, 16, and 17, shows these recalculated averages.

TABLE III

RECALCULATED AVERAGES, WATER EXCLUDED

	13 Olivine Basalt	14 Augite Andesite	15 Peridotite	16 Limburgite	17 Picrite
SiO_2	49.65	58.65	45.20	42.69	43.77
TiO_2	1.37	0.80	0.90	0.68	.....
Al_2O_3	16.16	17.67	5.25	15.18	15.37
Fe_2O_3	5.31	3.85	3.95	15.43	8.72
FeO	6.40	3.69	6.82		7.99
MnO	0.29	0.22	0.19	.....	.....
MgO	6.48	2.90	29.70	8.85	8.66
CaO	9.30	5.92	6.43	12.27	13.95
Na_2O	3.10	3.60	0.65	3.58	0.55
K_2O	1.48	2.40	0.77	1.19	0.49
P_2O_5	0.46	0.30	0.14	0.13	0.50

Sum, 100.00 in each case.

Table IV, Column 18, indicates the average composition of the olivine phenocrysts in basalt, according to Rammelsberg.[1] Column

TABLE IV

COMPOSITION OF PHENOCRYSTS IN OLIVINE BASALT

	18 Olivine (Rammelsberg)	19 Augite	20 Labradorite (Ab_3An_5)	21 Anorthite
SiO_2	41.01	47.72	55.55	43.16
TiO_2	.....	1.10	.....	.....
Al_2O_3	.....	6.31	28.35	36.72
Fe_2O_3	.....	3.12	.....	.....
FeO	9.83	5.31	.....	.....
MnO	.....	0.50	.....	.....
MgO	49.16	14.01	.....	.....
CaO	.....	20.71	10.36	20.12
Na_2O	.....	0.80	5.74	.....
K_2O	.....	0.42	.....	.....
Sp. gr. of crystal	ca. 3.40	ca. 3.30	2.700	2.75

[1] Quoted in Zirkel's *Lehrbuch der Petrographie*, 2d ed. (1893), Vol. I, p. 353.

19 gives the result of averaging 14 analyses of augite phenocrysts from basalt, dolerite, limburgite, and labradorite porphyrite, as stated in the appendix to Osann's compilation. Columns 20 and 21 represent typical analyses of labradorite and anorthite respectively.

By the settling-out of olivine, augite, and magnetite the molten lava or mother-liquor, must, when compared with the original basalt, be poorer in iron oxides, magnesia and lime, and richer in silica, alumina and the alkalies. The change in alumina might be slight, provided that the anorthite phenocrysts also settled out. Crystals of labradorite and andesine would slowly rise and enrich the upper part of the lava-column with silica, alumina, and soda. Chemically the average augite andesite appears to correspond to the mother-liquor, possibly bearing up-floated plagioclase crystals, while many of the ultra-basic rocks, picrite, limburgite, dunite, harzburgite, and other peridotites, correspond to those magmatic types developed deep within the lava-column by the settling of the phenocrysts.

2. *Observed cases of sunken and risen phenocrysts.*—A few instances of gravity differentiation accompanying the growth of phenocrysts in magma have been observed in rocks and also in artificial melts. Both Scrope, in 1825, and Charles Darwin, in 1844, published hypotheses, now classic, of such fractional crystallization in nature. Clarence King, in 1878, adopted their conclusion and added new examples studied by him at Kilauea. He broke asunder some of the thin, tongue-like flows of once very fluid basalt and found that in every case the bottom of the flow was thickly crowded with triclinic feldspars and augites, while the whole upper part of the stream was of nearly pure isotropic and acid glass.[1] He further remarked on the general absence of phenocrysts in some of the great Hawaiian flows; the crystals sank away into the conduit before eruption. Certain other Hawaiian flows described by E. S. Dana show the complementary feature of being ultra-basic and crowded with olivine crystals, which make up as much as 50 per cent. of the rock.[2] Neither at Kilauea nor at Mauna Loa, however, would one expect to find a notable differentiation of augite andesite. The extreme fluidity of lava-columns in both of the great pits seems to indicate general tempera-

[1] *U. S. Geol. Explor. 40th Parallel*, Sys. Geol., 1878, p. 716.

[2] J. D. Dana, *Characteristics of Volcanoes* (New York, 1891), p. 324.

tures above those at which even olivine can form. The "white" heat of the huge lava-fountains corresponds to a temperature of 1300° C. or over.[1] Granting that the Hawaiian conduits have always been so much superheated, it is not surprising that so few types of lava, other than olivine basalt, have been found on the island.

Iddings has described a striking case of the sinking of the augite phenocrysts, enriching a thick layer at the bottom of a 30-foot intrusive sheet on Electric Peak, Yellowstone Park.[2] It is not clear why so thin a sheet should have been differentiated and thus stand in contrast to hundreds of mapped sills of at least as great thickness, in which no differentiation is visible. Possibly the explanation is to be found in the fact that the Electric Peak sill is unusually rich in sulphur trioxide, chlorine, lithia, and "combined" water—substances which tend to lower the viscosity of magmas. In this case, though the magma was rather quickly chilled against the inclosing shales, the dissolved volatile matter maintained the fluidity long enough for the phenocrysts to fall to the bottom.

Against the hypothesis of fractional crystallization and gravitative sinking, it might be objected that the heavy minerals of early generation in gabbros and other plutonic types which have crystallized under slow-cooling conditions, are generally quite uniformly distributed through rock and show no concentration by gravity. There are, however, good reasons to believe that each plutonic magma, before any crystallization begins, is regularly cooled down several hundred degrees of the Centigrade scale below the melting-point of the rock resulting from the crystallization of the magma. The experiments of Oetling[3] and Amagat[4] show that pressure is a principal cause of this retardation of crystallization. According to Vélain[5] the retention of the volatile solvents, such as chlorides, would further tend to lower the temperature of crystallization in depth, while their escape at a volcanic vent would allow crystals to form at a higher

[1] Cf. H. Le Chatelier and O. Boudonard, High Temperature Measurements, trans. by G. Burgess, New York, 1904, p. 246.

[2] *Monograph* 32, Pt. 2, U. S. Geol. Surv., 1899, p. 82.

[3] *Tscher. min. u. petrog. Mitt.*, Vol. XVII, 1897, p. 332.

[4] *Comptes Rendus*, No. 16, 1893.

[5] *Op. cit.*, p. 181.

temperature and therefore during a less viscous stage of the magma's history. In an under-cooled silicate melt crystals must sink but slowly.

The crystallization of most plutonic magmas and of lavas at the earth's surface are thus believed to take place under strongly contrasted conditions. At the surface of a lava-column olivine, magnetite, augite, and plagioclase begin to form at high temperatures, when the viscosity is relatively low; the time-interval of crystallization for the whole magma is relatively long. Under plutonic conditions the same minerals crystallize at lower temperatures, when high viscosity is established and (because of under-cooling) the time-interval of crystallization is probably short.

Nevertheless, in some plutonic bodies of large size a certain amount of fractional crystallization and settlement of basic minerals may have actually taken place. Kemp has suggested that the anorthosites of the Adirondacks have been derived from more normal gabbro as a result of the sinking of the heavy constituents, either crystallized or still molten. He considers that the titaniferous magnetites of the region were erupted into the anorthosite after the anorthosite had consolidated, and implies that the molten ore has been derived from a *couche* which was formed from settled-out magnetite.[1] The relation of anorthosite and magnetite would, thus, be analogous to that postulated between augite andesite and certain olivine-rocks. Secondly, it is further possible that many basic contact-zones represent those parts of the respective intrusive masses where, on account of the relatively rapid cooling, the settling of basic minerals has been specially restrained, while the process has notably affected the composition of the slower-cooling interior of each mass. According to Kemp and Cushing[2] the huge anorthosite masses of the Adirondacks are characterized by wide contact-zones of rock relatively rich in pyroxene and magnetite (gabbro and anorthosite-gabbro). This gabbroid phase is usually finer grained and was presumably chilled more rapidly than the main body of the anorthosite.

[1] *Nineteenth Annual Report*, U. S. Geological Survey, pt. 3, 1899, p. 417.

[2] H. P. Cushing, *Geology of Franklin County*, 18th Report of the State Geologist (Albany, 1900), p. 101; *New York State Museum Bull. No. 95* (1905), p. 305 and *Bull. 115* (1907), p. 471.

It is obvious that the gravity-separation of phenocrysts in lava which has once escaped from its conduit and then cooled rapidly, will not be conspicuous in the average flow. The separation will be most pronounced in the upper levels of an active volcanic neck or lava-filled fissure.

The rising of phenocrysts in magma more dense than themselves has seldom been actually observed, partly for the reason that few phenocrysts are lighter than their matrix. Mercalli has described a case of the concentration of leucite phenocrysts (sp. gr. at 1100° C. about 2.42) in the surface layer of an 1883 flow of Vesuvian lava (sp. gr. molten at 1100° C. about 2.70).[1] An analogous instance is recorded by Morozewicz who found that tridymite (sp. gr. at 1300° C. 2.24), derived from converted quartz grains, floated to the top of a crucible in which he had melted two pounds of granite (sp. gr. at 1300° C. about 2.40).[2]

3. *Andesite actually observed to have been derived from basalt at an active volcano.*—But all deductive argument for the hypothesis must, in order to be entirely convincing, be supplemented with the positive facts of the field. The great value of Vélain's discovery in the Île de la Réunion (Bourbon) has surely never been adequately recognized in discussions on the origin of magmas.[3] A few weeks before his party reached Réunion the 8000-foot volcano at the southeastern end of the island erupted fluid lava at its summit and, simultaneously, other lava issued from a fissure on the flank of the volcano, a fissure which communicated with the main vent.

The lava issuing at the summit was relatively acid and had a composition apparently similar to that of the lava collected at the summit in the walls of the crater itself. The latter was analyzed by Vélain, with the following result:

SiO_2	57.49	Na_2O	3.64
Al_2O_3	16.41	K_2O	2.92
FeO	10.65	Loss on ignition	0.13
MnO	0.06		
MgO	1.23		100.05
CaO	7.52	Sp. gr.	2.79

[1] *Atti della Soc. ital. di scienze nat.*, Vol. XXVII, 1884.

[2] *Tscher. min. u. petrog. Mitt.*, Vol. XVIII, 1898, p. 332.

[3] C. Vélain, *Mission de l'Île Saint-Paul* (Paris, 1888), pp. 101 ff.

This rock appeared to be quite holocrystalline and was essentially composed of feldspar microclites, augite and iron oxide; olivine was a rare accessory. The augite and feldspar appear in large part to have crystallized at the same time.

The lava from the flanking fissure was examined and found to be very dense (sp. gr. 2.97) and much more basic than the lavas at the edge of the crater "qui datent pourtant de la même phase éruptive." This basic lava carried only 48.98 per cent of silica. It is rich in olivine, magnetite and augite, with which less abundant crystals of anorthite are associated.

> Ainsi, déversement d'une lave vitreuse, relativement riche en silice, par-dessus les bords du cratère comme un trop-plein, puis soutirage par des crevasses latérales, ouvertes à une assez grande distance du sommet, d'une lava tout à la fois plus basique et plus dense, chargée de péridot, mais se rapprochant de la précédente par la nature de son élément feldspathique (anorthite), tels sont les deux phénomènes consécutifs présentés par l'éruption de 1874. On peut les considérer comme représentant la marche habituelle des éruptions de ce volcan.[1]

The basic lava was observed to flow slowly, so that one may conclude that the temperature was well below 1200° C. or the point at which olivine begins to form in a cooling basalt. Other recorded flows of basaltic nature, such as that of 1812, ran with great speed, indicating higher temperatures and much lower kinetic viscosity. The temperature of the lavas within the vent is, thus, sufficiently variable to allow of their intermittent differentiation by the sinking of phenocrysts. In the process of time the island has been built up by alternating flows of olivine basalt, basic and acid augite andesites, and either true picritic rocks (described by Vélain) or their near relatives, ultrabasic basalts. Normal olivine basalt formed the original lava, whence, through fractional crystallization, the other types were derived.

4. *General field relations.*—The hypothesis implies that, in general, the derivation of augite andesite and olivine rocks from olivine basalt takes place in the relatively small openings represented by volcanic vents; secondly, that the effective differentiation occurs only when the lava column stands in the vent for a considerable time, and at temperatures ranging between 1200° and 1050° C.; thirdly, that the peri-

[1] C. Vélain, *op. cit.*, p. 182.

dotitic, limburgitic or picritic magma resulting from the remelting of the settled phenocrysts, would form at the base of the lava-column and would be considerably smaller in volume than the correlative andesite; fourthly, that the heavy, ultra-basic magma would oftener form intrusive than extrusive rocks, and would fill fissures either in the basal beds of the cone itself or in the older formations on which the cone rests; fifthly, that the primary basaltic magma is directly represented on the earth's surface where the lava was erupted rapidly in great volume, and at such temperatures that the phenocrysts of large size had not yet formed in abundance; and, sixthly, that augite andesite would be most often developed in and about the great volcanic cones, in the building of which the physical conditions and the duration of eruption were appropriate for pronounced fractional crystallization.

These various implications seem to be fairly matched by the facts of rock-distribution and rock-occurrence. The whole group of rocks here considered—basalts, andesites, peridotites, picrites, limburgites, etc., are consanguineous and several of them are commonly associated in the field. Where some of the derivatives are lacking in the existing outcrops, as in some of the British Columbia cases, the others may have been eroded away, or, on the other hand, have not yet been revealed by erosion. The ultrabasic rocks never form bodies of batholithic size but form dikes, sheets, "chonoliths,"[1] etc., and are thus always in such development as is explicable on this hypothesis. They form injected, not subjacent bodies. The olivine basalts are most largely developed in the vast lava-fields of the fissure-eruption type, where the emission of the primary lava has been too rapid for differentiation in the fissures. Augite andesite is most characteristically found in and about the greater cones, like those of the Andes mountain system or like most of the hundreds of very lofty cones rising from the floor of the deep sea. It has been already pointed out that the Hawaiian volcanoes carry superheated lavas, which, on account of the high temperature of the main body of each lava-column, cannot usually undergo pronounced fractional crystallization; yet the studies of J. D. and E. S. Dana show that some separation into olivine-free basalt and ultra-basic basalt has taken place before some of the

[1] *Journal of Geology*, Vol. XIII, 1905, p. 485 ff.

eruptions. King's observations warrant the belief that some differentiation by fractional crystallization occurs in the lava after it escapes from the calderas of Hawaii. However, the Hawaiian rocks are more allied to those of an Idaho or Oregon lava-flood than to the typical andesites of Ecuador. The poverty of Etna lava in phenocrysts may be explained as due to the partial differentiation of the primary olivine basalt.[1]

5. *Relation of augite andesite to other andesites.*—The hypothesis has been framed on the supposition that the primary basaltic magma has not been essentially affected by its solution or assimilation of chemically contrasted rock, material with which the lava makes contact as it rises or lies in the volcanic conduit. It is, however, most probable that the primary lava may in many cases absorb a certain amount of foreign material, either rock or fluid, and that the products of fractional crystallization must then vary notably from the few types so far mentioned. The process itself may be aided or retarded by such absorption, according as the absorption affects the temperatures of crystallization or the viscosity. Phenocrysts and ground-mass must change in chemical composition. Their separation by gravity would, then, produce magmatic materials not directly corresponding to augite andesite nor to any of the ultra-basic rocks formed directly from olivine basalt.

Hornblende andesites, mica andesites, dacites, etc., may, on this view, be derivatives of the primary basalt which has been modified by the assimilation of foreign rock-substance; while certain of the peridotites may represent some of the correlative differentiates of the compound lava. In a similar manner, one might possibly consider many lamprophyres and aplites as due to the analogous differentiation of their respective parent-magmas by the settling of basic minerals from the latter in its magmatic condition. It is not here the writer's purpose to discuss these possibilities in detail; they are noted rather to point to his belief that the commonly observed field associations and chemical relationships of augite andesite and other andesites are facts not opposed to the hypothesis outlined. It is, however, by no means intended to express the belief that *all* andesites or *all*

[1] Cf. H. Rosenbusch, *Mikros. Physiographie der massigen Gesteine*, 3d ed. (Leipzig, 1896), p. 1011.

peridotites have been formed through gravity separation of basic minerals; such a view is manifestly wrong.

6. *The rival hypothesis of magmatic differentiation.*—Finally, the hypothesis should meet the test of showing superiority over an obvious alternative suggestion. It might be conceived that augite andesite is due to the splitting of the basaltic magma before crystallization set in. In this view one must suppose that the splitting is due to a drastic change of physical conditions when the lava passes from abyssal levels to levels at or near the surface. The pressure is certainly very different in the two positions. However, no facts are in hand to show that a release of pressure causes immiscibility between two such magmas as molten andesite and molten peridotite, the two actually observed differentiates. If release of pressure alone caused the spontaneous splitting of olivine basalt into lighter andesite and heavier peridotite, we should very rarely expect to find true olivine basalt on the earth's surface, for most of these fluid lavas spend a considerable time in their conduits before being erupted. Against the idea is, further, the absence of any known physical reason why release of pressure should cause immiscibility. Experiments seem, on the contrary, to show that increase of pressure tends to promote immiscibility.

Immiscibility might conceivably ensue through a fall of temperature from a superheated condition, but there is no direct evidence that the phenomenon has a place in the history of volcanic cones or fissure-vents.

However probable may be the doctrine of immiscibility for certain magmas under plutonic conditions, we may regard the evidence on the problem as negative so far as volcanoes are concerned. The case may be summed up thus: The basaltic magma *may* split spontaneously into two or more magmas at a volcanic vent, but the phenocrysts of a molten basalt *must* sink while the lava undergoes the extremely slow cooling within the vent. Possibly both methods of differentiation are active. For the one advocated specially in this paper the physical conditions are quite simple and are largely understood quantitatively. The alternative view is at present a somewhat elusive conception for the petrologist and has few field-observations or compelling deductive considerations in its favor. It should, however, be added that the

writer believes in magmatic splitting under other conditions than those at the crater of a basalt volcano. Either hypothesis will, of course, recognize augite andesite as a derivative from olivine basalt; the balance of probability is here attributed to the hypothesis of fractional crystallization.

SUMMARY AND CONCLUSION

The purpose of the writer has been to state the results of correlating many scattered items of fact derived from experimental and field studies. The correlation seems strongly to support the early views of Scrope, Darwin, and others as to the efficiency of fractional crystallization in the formation of igneous rocks. It is only quite recently that this general hypothesis could be put on a quantitative basis. Even now there are needed many additional physical and chemical determinations before the hypothesis can reach its full measure of conviction for the petrologist. Nevertheless a compilation of the already established facts seems to show that the idea of rock-differentiation by the gravitative separation of certain minerals gains greatly in meaning, force, and usefulness when applied to actual rock-types and to actual petrographical provinces.

The hypothesis explains the origin of a considerable number of igneous rock-types. Augite andesite and many olivine-free basalts form what may be called one pole of the differentiation of olivine basalt. Picrite, limburgite, many peridotites and other ultra-basic types form the other polar group of differentiates. The conditions for the differentiation in the typical and general case, involve, in each case, a somewhat prolonged residence of the primary basalt in a volcanic vent in which the temperature varies from about 1200° to about 1050° C. The phenocrysts formed in the lava at these temperatures, must slowly but surely sink. They then collect in the lower part of the lava-column. While still undissolved, they may be erupted along with the fluid lava in which they rest, giving ultra-basic porphyritic lavas; or, as seems more probable, they are slowly dissolved in this lower, hotter part of the lava-column, forming one or more ultra-basic layers which, on injection, crystallize into peridotites or, following extrusion, develop picritic or limburgitic rocks.

The hypothesis is backed up by a comparison of the average olivine basalt and average augite andesite of the world; by a comparison of

the chemical nature of an individual and typical olivine basalt, its phenocrysts and its base; by the fortunate occurrence of simultaneous eruptions from the crater and low-lying lateral fissure at the Réunion volcano where Vélain shows the differentiation has taken place ideally; by the abundant proofs that heavy crystals do and must slowly sink and light crystals slowly rise in lavas, and in rock-melts; by the well-known facts of field-association and bodily development of augite andesite, olivine basalt and ultra-basic rocks throughout the different continents.

If the hypothesis correctly represents the facts and the augite andesites of the sea-floor volcanoes and of so many continental volcanoes are truly derivatives of olivine basalt, we have one more important link in the chain of argument leading to the belief that basaltic magma forms the universal substratum of the earth's crust today and has formed that substratum since Keewatin (early Archean) times. With this conception as a working theory the writer also connects the view that the crust overlying this basaltic substratum is stratified by density, so that the lower layer of the crust is crystallized basaltic magma (gabbro, possibly merging upward into anorthosite) and the upper layer is a composite of dominantly acid material. This latter is considered as made up largely of original granite or gneissic rock, similar to the staple fundamental gneiss of the pre-Cambrian—a layer probably less than thirty kilometers thick. This layer was crystallized in pre-Keewatin time; through it the basic Keewatin lavas were erupted; and through it basaltic magma has, from place to place and from time to time, ever since been erupted. The universal basaltic layer has thus been the effective source of the heat involved in the eruption of post-Keewatin igneous magmas. By the spontaneous differentiation of the primary basalt through fractional crystallization, the few rock-types specially discussed in this paper, have been locally derived. Most of the other eruptive rocks are, on this same working hypothesis, regarded as derived from the formation and differentiation of magmas which are the product of the solution of the acid, original gneissic shell and of its sedimentary veneer in the primary basalt. In other words, both the "syntectic"[1] (assimilation) theory and the fractional-crystallization theory seem to the writer to be essential and principal elements in the final solution of the genetic problem of the igneous rocks.

[1] F. Loewinson-Lessing, *Congrès géol. internat. Compte rendu*, 7th session, St. Petersburg, 1897, p. 375.

A TABLE OF INDEX OF REFRACTION AND BIREFRINGENCE OF ROCK-MAKING MINERALS

W. O. Hotchkiss

With regard to determining minerals in thin sections of rocks, index of refraction and birefringence are two of the most useful characteristics. These constants vary through wide ranges and comparatively few minerals possess the same or even nearly the same index. Consequently if the index can be determined even approximately the student has a most valuable starting-point to aid in his diagnosis of an unknown mineral.

The methods of determining the index described in Iddings' *Rock Minerals* furnish very delicate means of comparing the index of an unknown with that of a known mineral and sometimes will serve to determine the index closely enough for purposes of diagnosis, but it often occurs that the student would be able to determine a mineral much more readily if he had any means of actually measuring the index in a rough fashion. While instructing classes in petrology in the University of Wisconsin the writer spent some odd hours in trying to devise such a means, but did not succeed in finding anything simple enough for ordinary use. In connection with this work it was found somewhat difficult to get students to appreciate difference in index and make use of it in their studies, the temptation to identify a mineral simply by comparison—without a careful study of its constants—being too strong to resist. In the effort to overcome this tendency the accompanying table and diagram were constructed, and as they proved very satisfactory they are given here in the hope that others will find them as useful.

The diagram, as will be recognized, is simply an extension of Becke's diagram for the feldspars to include all minerals whose constants are known. The index is indicated by a short vertical line and the birefringence by a fine horizontal line. By giving all three indices for the optically biaxial minerals both the greatest and least possible birefrin-

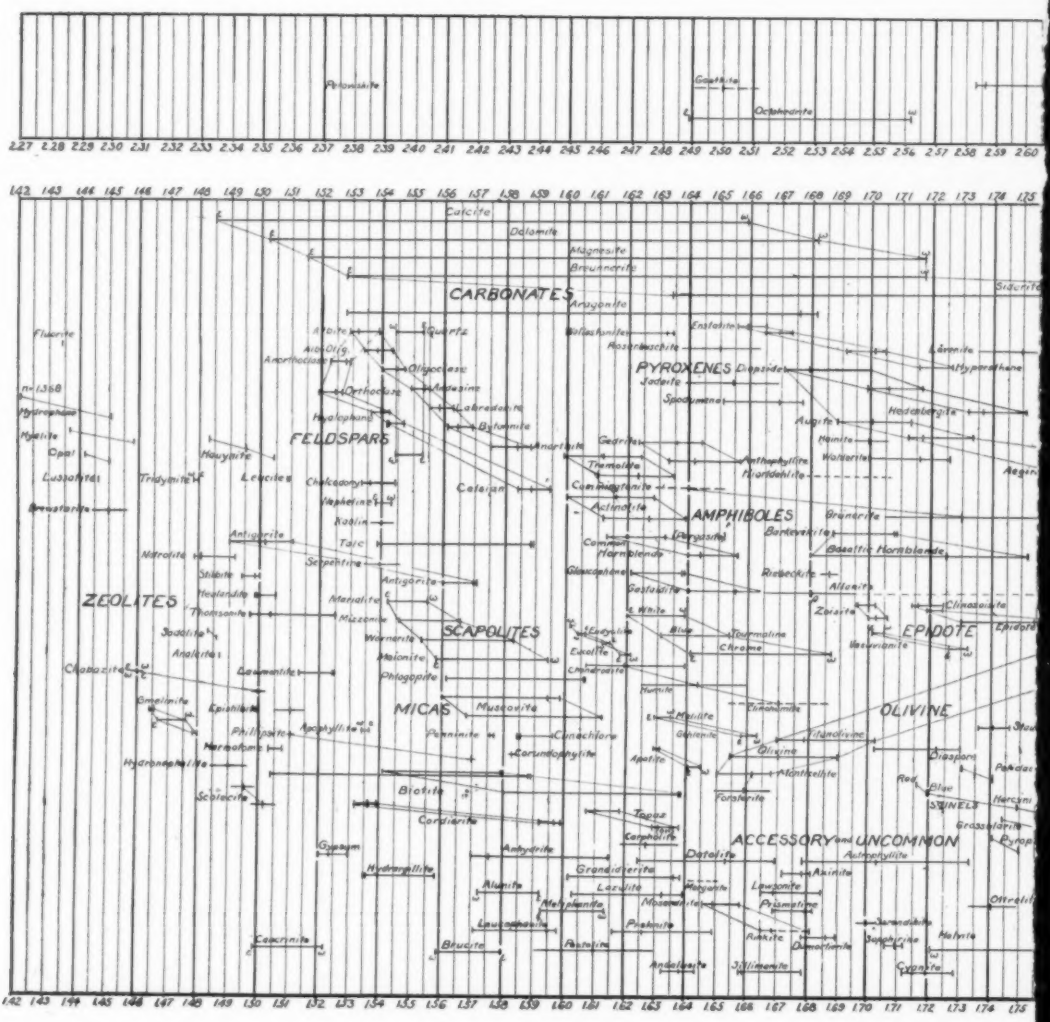
gence are shown. The total length of the line represents the maximum birefringence that any section of the mineral considered can possess. For many minerals the indices are only partly known. These are indicated by drawing the line representing the birefringence solid, when its approximate length is known, and any of the three indices is known. When an index is known, and the maximum birefringence is not known, it is represented by a dashed line either to the right or left or through the vertical line, according as the index is a, γ, or β, respectively. The first case is illustrated by Forsterite, $-\beta = 1.659$, and the last three by Clinohumite, $-\beta = 1.670$, in which the maximum birefringence is not known.

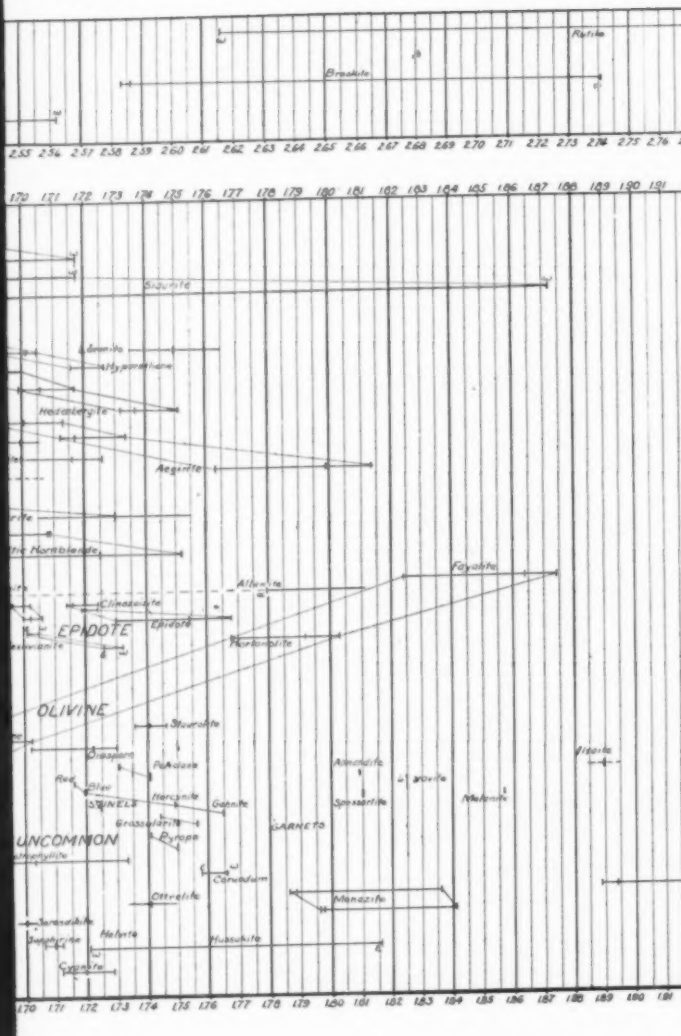
Minerals do not have constant unchangeable indices. The indices vary with composition and with change in physical conditions. These variations are indicated by giving both the lowest and highest sets of indices and connecting the similar indices by fine diagonal lines. This scheme serves to connect and group the various members of mineral series, such as the carbonates, the feldspars, the pyroxences, the olivine group, etc. It also serves to indicate change in sign of uniaxial minerals such as occurs in the eucolite-eudyalite series.

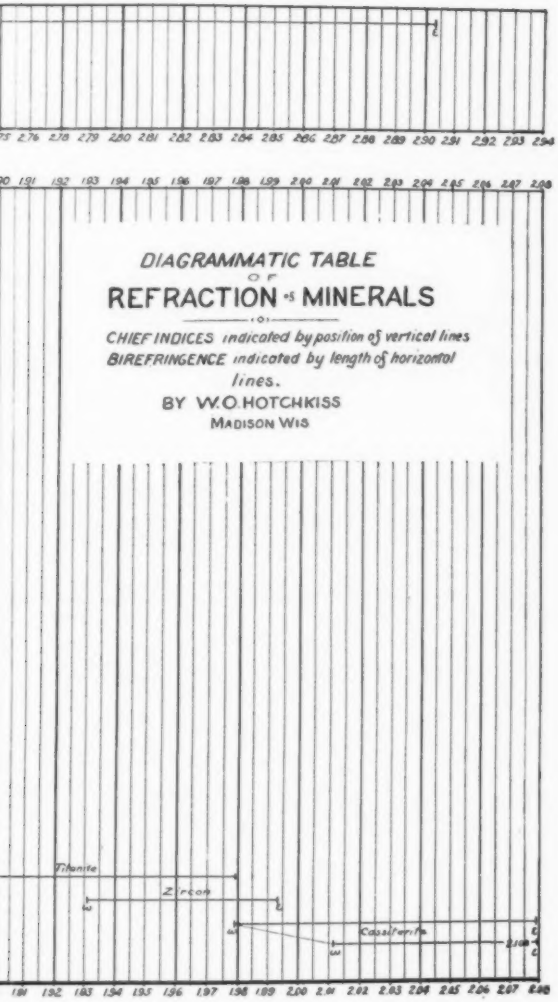
As far as possible the minerals are grouped in the diagram according to their relations. The most important rock-making groups are put together so as to facilitate comparison. Thus the carbonates are together, and similarily the amphiboles, pyroxenes, the olivine group, the mica group, the feldspars and quartz. About these are the other minerals—those with low indices, such as fluorite, leucite, and the zeolites at the left, and the large numbers of "accessory and uncommon" minerals to the right and below.

An inspection of the diagram will indicate its usefulness. The space between any two heavy vertical lines representing a difference in index of 0.020, or, roughly, two times the maximum birefringence of quartz, will be seen to contain comparatively few minerals, and usually there is a difference in the birefringence of these which serves for their easy distinction.

The diagram serves for the ready finding of any mineral corresponding to a known index. In order to find the indices of a known mineral a table arranged alphabetically is given. The table gives the indices


CARBONATES
PYROXENES
FELDSPARS
AMPHIBOLES
ZEOLITES
SCAPOLITES
MICAS
EPIDOTE
OLIVINE
ACCESSORY and UNCOMMON
Calcite
Dolomite
Magnesite
Braunnerite
Aragonite
Quartz
Tridymite
Leucite
Nephelina
Sodalite
Analcite
Chabazite
Natrolite
Stilbite
Heulandite
Thomsonite
Mesolite
Scolecite
Talc
Antigorite
Serpentine
Wernerite
Meionite
Phlogopite
Muscovite
Biotite
Cordierite
Tourmaline
Chrome
Zoisite
Vesuvianite
Olivine
Forsterite
Tephroite
Topaz
Kornerupine
Datolite
Axinite
Grandidierite
Lazulite
Alunite
Hydrargillite
Gypsum
Anhydrite
Boracite
Pectolite
Prehnite
Rutile
Sillimanite
Cyanite
Staurolite
Hercynite
Grossularite
Pyrope
Almandite
Autunite
Meionite
Scapolite
Enstatite
Rosenbuschite
Diopside
Jadeite
Spodumene
Augite
Hedenbergite
Hypersthene
Hornblende
Basaltic Hornblende
Actinolite
Tremolite
Anthophyllite
Hastingsite
Riebeckite
Arfvedsonite
Barkevikite
Orthoclase
Albite
Oligoclase
Andesine
Labradorite
Bytownite
Anorthite
Microcline
Hyalophane
Celsian
Chalcedony
Opal
Tridymite
Lussatite
Hauynite
Nosean
Cancrinite
Elaeolite
Pyrophyllite
Talc
Chlorite
Serpentine
Kaolin
Margarite
Damourite
Sericite
Paragonite
Lepidolite
Lithia Mica
Lepidomelane
Penninite
Clinochlore
Corundophyllite
Chloritoid
Staurolite
Apatite
Fluorite
Pyrite
Magnetite
Ilmenite
Rutile
Zircon
Titanite
Perovskite
Brookite
Cassiterite
Wolframite
Scheelite
Molybdenite
Graphite
Sphene
Allanite
Orthite
Monazite
Xenotime
Euxenite
Fergusonite
Columbite
Samarskite
Pyrochlore
Blende
Galenite
Chalcopyrite
Pyrite
Bornite
Chalcocite
Tetrahedrite
Enargite
Tennantite
Stibnite
Realgar
Orpiment
Cinnabar
Native Gold
Native Silver
Native Copper
Native Bismuth
Native Arsenic
Native Antimony
Native Sulphur
Native Graphite
Native Platinum
Native Iridium
Native Osmium
Native Tellurium
Native Selenium
Native Mercury
Native Lead
Native Tin
Native Zinc
Native Iron
Native Nickel
Native Cobalt
Native Aluminium
Native Magnesium
Native Manganese
Native Chromium
Native Vanadium
Native Tungsten
Native Molybdenum
Native Titanium
Native Zirconium
Native Cerium
Native Lanthanum
Native Yttrium
Native Erbium
Native Terbium
Native Ytterbium
Native Scandium
Native Gallium
Native Indium
Native Thallium
Native Germanium
Native Tantalum
Native Niobium
Native Rhenium
Native Ruthenium
Native Rhodium
Native Palladium
Native Osmiridium
Native Iridosmine
Native Platinum
Native Gold
Native Silver
Native Copper
Native Bismuth
Native Arsenic
Native Antimony
Native Sulphur
Native Graphite
Native Platinum
Native Iridium
Native Osmium
Native Tellurium
Native Selenium
Native Mercury
Native Lead
Native Tin
Native Zinc
Native Iron
Native Nickel
Native Cobalt
Native Aluminium
Native Magnesium
Native Manganese
Native Chromium
Native Vanadium
Native Tungsten
Native Molybdenum
Native Titanium
Native Zirconium
Native Cerium
Native Lanthanum
Native Yttrium
Native Erbium
Native Terbium
Native Ytterbium
Native Scandium
Native Gallium
Native Indium
Native Thallium
Native Germanium
Native Tantalum
Native Niobium
Native Rhenium
Native Ruthenium
Native Rhodium
Native Palladium
Native Osmiridium
Native Iridosmine


Rutile
Brookite
Sillimanite
Hypersthene
Hornblende
Aegirite
Fayalite
Albite
Clinozoisite
EPIDOTE
Epidote
Hornblende
OLIVINE
Staurolite
Diopside
Almandite
Spessartite
Melanite
Hercynite
Gahnite
GARNETS
Grossularite
Pyrope
UNCOMMON
Chondrodite
Corundum
Cassiterite
Monazite
Sphene
Fluorite
Hematite
Cyanite


DIAGRAMMATIC TABLE
OF
REFRACTION of MINERALS
CHIEF INDICES indicated by position of vertical lines
BIREFRINGENCE indicated by length of horizontal lines.
BY W.O. HOTCHKISS
MADISON WIS
Titanite
Zircon
Cassiterite

Mineral	Indices of Refraction			Maximum Birefringence
	α; ϵ; a	ω; β	γ	
Actinolite	1.612	1.627	1.639	0.027
	1.600	1.616	1.628	0.028
Aegirite	1.763	1.799	1.813	0.040
Albite	1.529	1.532	1.539	0.010
Allanite	1.78	?	?	0.032
	?	1.68	?	.....
Almandite	1.809	.....	.....	.....
Alunite	1.592	1.572	.....	0.020
Analcite	1.487	.....	.....	.....
Andalusite	1.632	1.638	1.643	0.011
Andesine	1.549	1.553	1.555	0.006
Anhydrite	1.570	1.576	1.614	0.044
Anomite (Var. Biotite)	.....	.....	.....	.....
Anorthite	1.575	1.584	1.588	0.013
Anorthoclase	1.523	1.528	1.529	0.006
Antophyllite	1.633	1.642	1.657	0.024
	1.629	1.630	1.640	0.011
Antigorite	1.490	1.502	1.511	0.022
	1.560	1.570	1.571	0.011
Apatite	1.629	1.631	.....	0.002
	1.641	1.645	.....	0.004
Apophyllite	1.536	1.534	.....	0.002
Aragonite	1.528	1.676	1.681	0.153
	1.534	1.689	1.694	0.160
Astrophyllite	1.678	1.703	1.733	0.055
Augite	1.688	1.701	1.713	0.025
	1.712	1.717	1.733	0.021
Axinite	1.672	1.678	1.681	0.009
Barkevikite	1.687	1.707	1.708	0.021
Biotite	1.541	?	1.580	0.039
	1.580	?	1.638	0.058
	1.504	1.589	1.589	0.085
Breislakite (Var. Ilvaite)	.....	.....	.....	.....
Breunnerite	1.528	1.717	.....	0.189
Brewsterite	?	1.45	?	0.012
Bronzite (betw. Enstatite and Hypersthene)	.....	.....	.....	.....
Brookite	2.583	2.586	2.741	0.158
Brucite	1.580	1.559	.....	0.021
Bytownite	1.561	1.564	1.569	0.008
Calcite	1.486	1.658	.....	0.172
Cancrinite	1.499	1.522	.....	0.023
Carpholite	1.627	?	?	0.022
Cassiterite	1.979	2.080	.....	0.101
	2.012	2.108	.....	0.096
Celsian	1.584	1.587	1.594	0.010
Chabazite	1.5	?	.....	0.003
	1.46	?	.....	0.002
Chalcedony	1.533	1.536	1.544	0.011
Chiastolite (see Andalusite)	.....	.....	.....	.....
Chloritoid (see Ottrelite)	.....	.....	.....	.....
Chondrodite	1.607	1.619	1.639	0.030
Chrysolite (see Olivine)	.....	.....	.....	.....
Clinozoisite	1.714	1.716	1.724	0.010
Clinohumite	?	1.670	?	.....

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; α	ω; β	γ	
Clinochlore	1.585	1.586	1.596	0.011
Cordierite	1.532	1.536	1.539	0.007
	1.592	1.597	1.599	0.007
Corundophilite	?	1.583	?	.....
Corundum	1.758	1.766	.....	0.008
Cummingtonite	?	1.64	?	.....
Cyanite	1.712	1.720	1.728	0.016
Danalite (see Helvite)	.....	.....	.....	.....
Datolite	1.624	1.653	1.669	0.045
Diallage (see Diopside, Hedenbergite, and Augite)	.....	.....	.....	.....
Diaspore	1.702	1.722	1.730	0.028
Diopside	1.699	1.706	1.717	0.018
	1.671	1.678	1.700	0.029
Dipyre (see Mizzonite)	.....	.....	.....	.....
Disthene (see Cyanite)	.....	.....	.....	.....
Dolomite	1.503	1.682	.....	0.179
Dumortierite	1.678	1.686	1.689	0.011
Enstatite	1.656	1.659	1.665	0.009
	1.665	1.669	1.674	0.009
Epidote	1.730	1.754	1.768	0.038
Epistilbite	?	1.51	?	0.010
Eucolite	1.618	1.621	.....	0.003
Eudyalite	1.614	1.612	.....	0.002
	1.606	1.604	.....	0.002
Fayalite	1.824	1.864	1.874	0.050
Fluorite	1.434	.....	.....	.....
Forsterite	?	1.659	?	.....
Gahnite	1.765	.....	.....	.....
Gastaldite	1.640	1.656	?	0.018
	.....	.....	.....	0.024
Gedrite	1.623	1.636	1.644	0.021
Gehlenite	1.658	1.663	.....	0.005
Gibbsite (see Hydrargillite)	.....	.....	.....	.....
Glaucophane	1.621	1.638	1.639	0.018
Gmelinite	1.467	1.476	.....	0.009
	1.464	1.465	.....	0.001
	1.478	1.480	.....	0.002
Goethite	?	2.5	?	.....
Grandidierite	1.602	1.636	1.638	0.036
Grossularite	1.744	.....	.....	.....
	1.757	.....	.....	.....
Grünerite	?	1.73	?	0.056
Gypsum	1.520	1.523	1.530	0.010
Hainite	?	1.7	?	0.012
Harmotome	1.503	?	1.508	0.005
Hiortdahlite	?	1.68	?	0.017
	?	1.71	?	0.020
Hedenbergite	1.732	1.737	1.751	0.019
Hauynite	1.496	.....	.....	.....
	1.504	.....	.....	.....
	1.483	.....	.....	.....
Helvite	1.739	.....	.....	.....
Hercynite	1.749	.....	.....	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Heulandite	1.498	1.499	1.505	0.007
Green Hornblende	1.640	1.643	1.656	0.016
Basaltic Hornblende	1.680	1.725	1.752	0.072
Hortonolite	1.768	1.792	1.803	0.035
Humite	?	1.643	?	0.038
Hussakite	1.816	1.721	.....	0.005
Hyalite	1.437	.....	.....	.....
	1.458	.....	.....	.....
Hyalophane: Or_4Ce_1	1.537	1.540	1.542	0.005
Or_7Ce_3	1.542	1.542	1.547	0.005
Hydrargillite	1.535	1.535	1.558	0.023
Hydronephelite	1.49	?	.....	0.012
Hydrophane	1.368	.....	.....	.....
	1.451	.....	.....	.....
Hypersthene	1.692	1.702	1.705	0.013
	1.716	?	1.727	0.011
Ilvaite	?	1.89	?	.....
Jadeite	?	1.654	?	0.020
Kaolin	1.54	?	?	0.008
Kornerupine (see Prismatine)	.....	.....	.....	.....
Labradorite	1.555	1.558	1.563	0.008
Laumontite	1.513	1.524	1.525	0.012
Låvenite	?	1.750	?	0.030
Lawsonite	1.665	1.669	1.684	0.019
Lazulite	1.603	1.632	1.639	0.036
Leucite	1.509	1.508	.....	0.001
Leucophanite	1.571	1.595	1.598	0.027
Lievrite (see Ilvaite)	.....	.....	.....	.....
Lussatite	1.446	.....	.....	.....
Magnesite	1.515	1.717	.....	0.202
Margarite	?	1.64	?	0.009
	?	1.65	?	.....
Marialite	1.542	1.555	.....	0.013
Meionite	1.557	1.594	.....	0.037
Melanite	1.857	.....	.....	.....
Melilite	1.629	1.634	.....	0.005
Meliphanite	1.593	1.613	.....	0.020
Mizzonite	1.546	1.566	.....	0.020
Monazite	1.796	1.797	1.841	0.045
	1.786	1.789	1.837	0.051
Monticellite	1.650	1.662	1.668	0.018
Mosandrite	1.646	1.649	1.658	0.012
Muscovite	1.560	1.594	1.598	0.038
	1.569	1.605	1.612	0.043
Natrolite	1.478	1.482	1.492	0.014
Nephelite	1.538	1.543	.....	0.005
Noselite	1.483	.....	.....	.....
	1.504	.....	.....	.....
Octahedrite	2.489	2.562	.....	0.073
Oligoclase	1.540	1.544	1.547	0.007
Olivine	1.654	1.670	1.689	0.035
Opal	1.442	.....	.....	.....
	1.450	.....	.....	.....
Orthite (see Allanite)	.....	.....	.....	.....

Mineral	Indices of Refraction			Maximum Bi-refringence
	n; ϵ; α	ω; β	γ	
Orthoclase	1.519	1.524	1.527	0.008
Ottrelite	?	1.741	?	0.016
Pargasite (common Hornblende)	1.613	1.620	1.632	0.019
Pectolite	?	1.61	?	0.038
Penninite	1.576	1.577	.....	0.001
Periclase	1.731	.....	.....	.....
	1.741	.....	.....	.....
Perowskite	2.38	.....	.....	.....
Phillipsite	?	1.51	?	.....
	?	1.57	?	0.003
Phlogopite	1.562	1.606	1.606	0.044
Picotite (see Spinel)	.....	.....	.....	.....
Pleonaste (see Spinel)	.....	.....	.....	.....
Prismatine	1.669	1.680	1.682	0.013
Prehnite	1.616	1.626	1.649	0.033
Pyrope	1.741	.....	.....	.....
	1.750	.....	.....	.....
Quartz	1.553	1.544	.....	0.009
Riebeckite	1.687	?	?	0.005
Rinkite	1.665	1.668	?	0.003
Rosenbuschite	?	1.65	?	0.026
Rutile	2.903	2.616	.....	0.287
Sapphirine	1.706	1.709	1.712	0.006
Scapolite (see Wernerite)	.....	.....	.....	.....
Scolecite	?	1.495	?	0.008
	?	1.502	?	.....
Serendibite	?	1.7	?	weak
Serpentine	?	1.54	?	0.013
Siderite	1.634	1.872	.....	0.238
Sillimanite	1.658	1.659	1.678	0.020
Sismondine (see Ottrelite)	.....	.....	.....	.....
Sodalite	1.483	.....	.....	.....
	1.486	.....	.....	.....
Spessartite	1.810	.....	.....	.....
Spinels (Red)	1.716	.....	.....	.....
(Blue)	1.720	.....	.....	.....
Spodumene	1.651	1.669	1.677	0.026
Staurolite	1.736	1.741	1.746	0.010
Stilbite	1.494	1.498	1.500	0.006
Talc	1.539	1.589	1.589	0.050
Thomsonite	1.497	1.503	1.525	0.028
Titanite	1.888	1.894	1.979	0.091
Titanolivine	1.669	1.678	1.702	0.033
Topaz (Fl)	1.607	1.610	1.618	0.011
(OH)	1.629	1.631	1.638	0.009
Tourmaline (White)	1.620	1.639	.....	0.019
(Blue)	1.631	1.653	.....	0.022
(Chrome)	1.641	1.687	.....	0.046
Tremolite	1.599	1.612	1.624	0.025
	1.609	1.623	1.635	0.026
Tridymite	1.479	1.477	.....	0.002
Uvarovite	1.838	.....	.....	.....
Vesuvianite	1.701	1.705	.....	0.004
	1.726	1.732	.....	0.006

Mineral	Indices of Refraction			Maximum Birefringence
	n; ϵ; a	ω; β	γ	
Wernerite	1.553	1.583	.....	0.030
Wöhlerite	1.700	1.716	1.726	0.026
Wollastonite	1.619	1.632	1.634	0.015
Zircon	1.993	1.931	.....	0.062
Zoisite	1.696	1.696	1.702	0.006
	1.700	1.702	1.706	0.006

published in Rosenbusch-Wülfing, and all that are shown in the diagram. The first column gives n for isometric, ϵ for uniaxial, or a for biaxial minerals. The second column gives ω for uniaxial or β for biaxial minerals, as the case may be. The third column gives γ and the fourth gives the maximum birefringence. When an index is lacking the fact is indicated by a question mark.

The diagram illustrates very forcibly the need for some simple microscopic means of measuring the indices of minerals in thin sections. Various means are available at present for finding the index of mineral faces one or two millimeters in diameter, but no successful apparatus which will serve to use as an attachment to an ordinary petrographic microscope has been devised. The writer has had to give up any idea of working on such a help for students, as his interests are directed into other branches of the science, but it is hoped that this will fall into the hands of someone who will be interested enough to solve the problem.

HIGHLY FOLDED BETWEEN NON-FOLDED STRATA AT TRENTON FALLS, N. Y.

W. J. MILLER
Hamilton College, Clinton, N. Y.

While engaged in field-work for the New York Geological Survey during the summer of 1907, excellent examples of highly folded between non-folded strata were observed at Trenton Falls, north of Utica, New York.[1] The phenomenon occurs in the classic Trenton limestone at its type locality. Vanuxem[2] and T. G. White[3] are the only ones who have described and attempted to explain the phenomenon at Trenton Falls.

Layers of highly folded and broken limestone included between perfectly straight and undisturbed limestone layers are well exhibited along the sides of the gorge at Trenton Falls. The impure limestone layers of both the folded and the non-folded portions average only a few inches in thickness and are separated by thin shale bands. The folded beds lie at two distinct horizons within the limestone formation which here shows a thickness of 270 feet. Prosser and Cummings[4] have made careful measurements of the thickness of the Trenton limestone at this locality. According to them the base of the lower folded zone lies 144 feet below the top of the Trenton. This contorted zone is about four or five feet thick and is visible only opposite the top of the lower part of High Fall and in the upper end of the gorge near Prospect village where the strata are highly inclined. It is well shown in Fig. A, Pl. III of White's article. Prosser and Cummings do not definitely refer to the upper folded zone in their paper,

[1] Published by permission of Dr. J. M. Clarke, State Geologist of New York.

[2] *Natural History of New York—Geology of the Third District*, p. 53.

[3] "The Faunas of the Upper Ordovician Strata at Trenton Falls, Oneida Co., N. Y.," *Transactions of the N. Y. Academy of Sciences*, Vol. XV, pp. 71–96.

[4] Prosser and Cummings, *Sections and Thickness of the Lower Silurian Formations on West Canada Creek and in the Mohawk Valley*, 15th Annual Report of the N. Y. State Geologist, pp. 615–27.

but its base occurs well down in their zone A^8 or about sixty-five to seventy feet below the top of the Trenton limestone. This contorted zone is about eight or ten feet thick and is well shown along the path opposite High Fall. From this point it may be traced along the sides of the gorge for nearly two miles to near the village of Prospect.

Within the folded zones the layers are, in rare instances, scarcely disturbed; sometimes they are only gently folded; most commonly they are highly twisted or contorted; while occasionally some of the layers are broken and pushed or faulted over others.

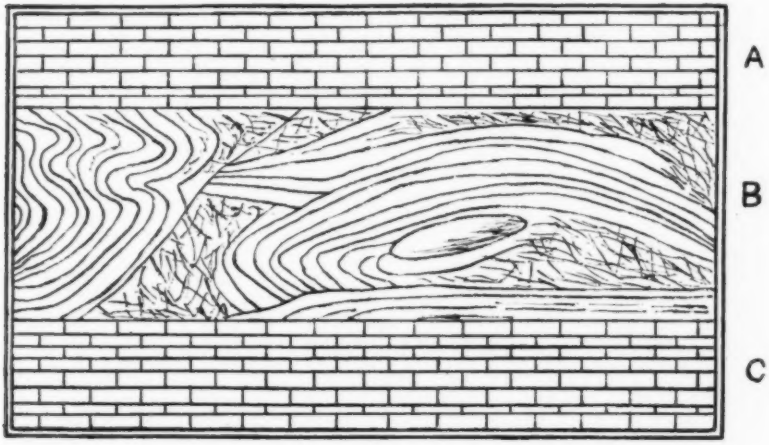


FIG. 1.—Sketch showing highly folded and broken limestone layers between undisturbed beds as seen along the foot-path opposite the top of High Fall, Trenton Falls, N. Y. Scale: one inch = six feet.

In those places where the folding has not been carried to an extreme, numerous observations show the axes of the folds to run generally from N. 50° E. to N. 65° E. The strike of these minor folds corresponds closely to the strike of a fault which the writer has found to extend from Prospect village past the village of Trenton. Also the whole Trenton limestone formation has, in this vicinity, been thrown into a number of very low folds which show about the same strike as above given.

It should be noted that these highly folded layers occur only in a

very local district. Numerous observations are not possible because of the heavy drift covered areas, but, as far as can be ascertained, these highly folded layers are visible only in the Trenton Falls gorge and in the bed of Cincinnati creek, one and one-half miles southwest of Prospect. Along Mill creek, near Gravesville, several miles to the southeast, most of the Trenton section is exposed but the folded layers have not been found there.

Similar phenomena of highly folded between non-folded strata have been observed in the stratified clay banks of Pleistocene age along Black River to the north of Trenton Falls and also in the banks along the canal feeder west of Forestport. The latter occurrence has been described and figured by Vanuxem.[1]

CAUSE OF THE FOLDING[2]

Vanuxem[3] states that the folded layers are more thoroughly crystalline than the undisturbed layers above and below and that as the material of the disturbed layers was being crystallized it caused an expansion which manifested itself laterally by throwing the layers into folds. However, a careful examination of the layers in the folded zone and those above and below fails to show any real difference in degree of crystallization. Even if such a difference in degree of crystallization were present, it is difficult to see how simple crystallization of the mass could bring about such a considerable lateral expansion.

T. G. White[4] cites Professor W. O. Crosby as suggesting that the folds may have been caused by the great weight of overlying strata. According to this view it is extremely difficult to explain the sharp and even overturned folds and the minor thrust faults which imply a distinct shortening of the layers within the folded zones.

In many places the structure of the upper folded zone greatly simulates cross-bedding and the writer was at first of the opinion that it, in reality, did show cross-bedding. The close association, in the same zone, of truly folded and broken strata soon caused this idea

[1] *Op. cit.*, pp. 214, 215.

[2] The writer here wishes to express his thanks to Dr. C. K. Swartz of the Johns Hopkins University for suggestions regarding the cause of the folding.

[3] *Loc. cit.*, p. 90.

[4] *Op. cit.*, pp. 88–90.

to be cast aside. White[1] gives photographs showing supposed overlap structure and channel filling. These structures appear to be merely parts of the disturbed zones, described in this paper, where the beds have been broken or only gently folded.

It has occurred to the writer that the phenomenon might have been due to a lateral compression within the region, which caused most of the limestone beds to become denser without being greatly folded, while certain other layers yielded to the compressive force by folding. Such an explanation would imply a difference in texture between the folded and non-folded strata, but such a difference is not noticeable. Also it would seem to assume that the folded zone was more rigid while the evidence appears to indicate, if anything, that it was less rigid.

It is thought that the folded structure at Trenton Falls was in reality caused by a differential movement within the mass of the Trenton limestone. That the whole body of the limestone has been moved is clearly demonstrated by the existence of a thrust fault, of considerable throw, passing Prospect village. The displacement was sufficient to cause beds of the middle Trenton to slide over beds of the upper Trenton. Near the fault-plane the beds on the upthrow side are bent upward at angles of from thirty to forty degrees. The following figure, shows the relation of the fault to the folded zones.

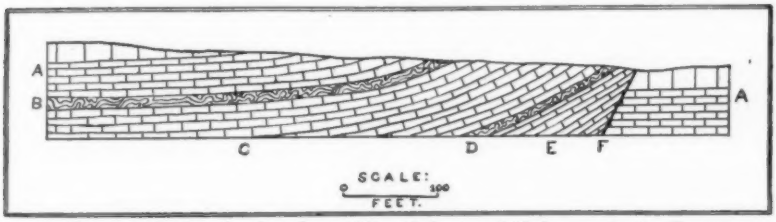


FIG. 2.—Section showing the position of the two folded zones in the Trenton limestone and their relation to the thrust fault at Prospect, near Trenton Falls, N. Y.

It is easy to see how when the force of compression was brought to bear in the region there would be a tendency for the upper Trenton beds on the upthrow side to move more easily and consequently faster than the lower Trenton beds. For instance the portion A in

[1] *Op. cit.*, Pl. III, Fig. B, and Pl. IV, Fig. B.

Fig. 2 being separated from C by an intermediate mass B of slightly less rigidity would slide over C and cause the portion B to become ruffled or folded. Occasionally parts of zone B would become fractured or faulted. The portion B would need to be only slightly less rigid than the adjacent portions. The somewhat thinner limestone layers separated by thicker shale partings would be sufficient to cause the part B to be thus less rigid. A similar explanation would also apply to the lower folded zone. The folded zones thus merely indicate horizons of weakness along which the differential movement has taken place.

As thus explained it is evident why the strike of the minor folds, the strike of the fault, and the strike of the large low folds of the region should all be parallel, since all these phenomena were produced by the same pressure. Also the local character of the phenomena under discussion is readily explained, since the conditions for their formation exist only in the vicinity of the fault.

Where phenomena of this kind occur even in regions of low folds, but without faults, it is thought that the above explanation will suffice, because during the process of folding there would be more or less of a tendency for certain strata to slide over others. Where the conditions of relative rigidity, etc., were favorable, certain strata just beneath the sliding masses might become ruffled or folded.

The locally folded clay layers between non-folded layers along Black River, above mentioned, are to be explained in a somewhat similar manner. Vanuxem says: "The layers show a series of contortions of different kinds, for which no cause can reasonably be assigned but different degress of lateral pressure." Since there is no noticeable difference between the characters of the disturbed and the undisturbed beds and since the intensity of the folding is often so great, Vanuxem's explanation is not at all satisfactory. The required differences in degree of lateral pressure are altogether too great. The writer believes that, in principle, the explanation given for the Trenton Falls occurrences applies here also, although in the case of the clay beds the movement of the upper over the lower masses may have been caused by ice action or by having been pulled down the hillsides by gravity. Or as Salisbury and Atwood[1] have suggested for such

[1] *Jour. Geol.*, Vol. V, 1897, p. 143.

a phenomenon in Pleistocene clay, the cause may have been lake ice or "the grounding of an iceberg on the surface before the overlying layers were deposited." In any case the cause of the movement in these superficial clays appears to be different from that of the ancient Trenton limestone.

GEOTECTONICS OF THE ESTANCIA PLAINS

CHARLES R. KEYES

Prefatory.—The Estancia Plains lie in central New Mexico. They form the extreme northern portion of the vast Mexican tableland. In length they extend a distance of 150 miles; in width about 30 miles.

Previous to the year 1900 the Estancia Plains were regarded as the highest and driest bolson east of the continental divide. For this reason, if for no other, the underground-water possibilities of this region offered a theme for consideration that was of great interest. Large industrial interests made possible the investigations necessary to decipher the geological structure. Three new lines of railway were under construction across these plains and good water-supplies became a matter of prime import.

General features.—Geographically the Estancia Plains are located at the juncture of the four greatest physiographic provinces of our continent: The Great Plains, the Rocky Mountains, the Mexican tableland, and the Colorado plateau. There are within the borders of the Estancia area three very distinct types of orogenic structures. These are superimposed upon a general and very remarkable epeirogenic uprase.

At the north and east is the Rocky Mountain type, illustrating tremendous compressive action. Over the west and south the basin-range type of structure is finely shown in the immense tilted block mountains. In the west-central portion is the laccolithic type, represented by four distinct dome-shaped masses which have spread apart Cretacic strata.

In the main, the geologic structure of the Estancia Plains is that of a broad trough, but there are many interruptions and local deformations (Fig. 1). As compared with the structure of the Jornada del Muerto[1] farther south there is not nearly the regularity (compare

[1] *Water Supply Paper No. 123*, U. S. Geological Survey, 1904.

with Fig. 2). As in the case of the latter plain the general aspect is that of a wide shallow valley which has a tendency to impart something of a synclinal character to the substructure. This apparent general relief feature, however, bears no relationship to the arrange-

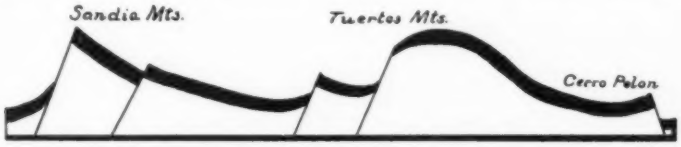


FIG. 1.—General structure of Estancia Plains.

ment of the formations beneath. The surface of the plains is not a stratum-plane, as is naturally at first inferred, but a plane worn out in part at least on the beveled edges of the strata below, which lie at many different angles and dip in many different directions.

This general structure of the plains appears to have been the characteristic feature of the region before their continuity was interrupted by the faulting which gave rise to the block mountains, and by the laccolithic intrusions.

In most of the parallel bolsons and valleys which are found in the high tableland region of New Mexico the bounding mountain blocks are so tilted that across some plains great fault-scarps face each other, as in the case of the Jarilla bolson immediately south of the Estancia district. Here the abrupt fault-scarp of the Sierra San

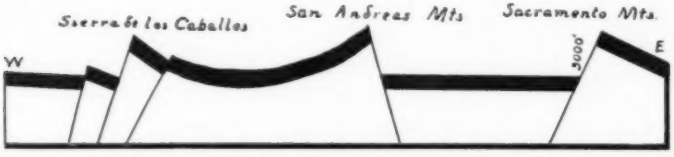


FIG. 2.—Structure of the basin ranges in central New Mexico.

Andreas, rising over 3,000 feet above the level of the plains, faces the equally abrupt scarp of the Sacramento Range to the east which rises even higher. In other instances, as in the Jornada to the southwest of the Estancia Plains, the main portion of the bolson is flanked on either side by the gentle backslopes of the monoclinal blocks. The fundamental plan of geologic structure is best indicated by diagram

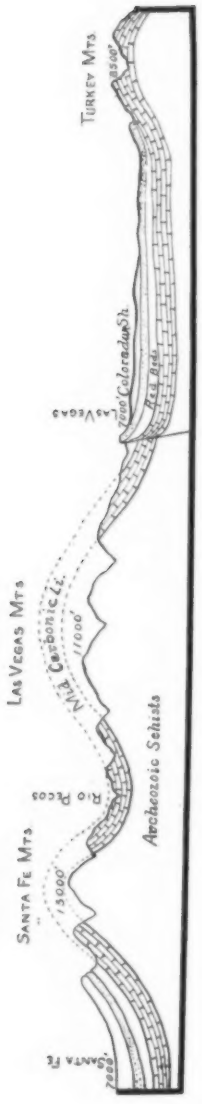


FIG. 3.—Geologic cross-section of the southern Rocky Mountains.

(Fig. 2). A similar arrangement representing the structure of the Estancia Plains is shown in Fig. 1.

The important factor to be taken into account in this region is the fact that the local geologic structure is not nearly so simple as it may at first glance appear. Everywhere there is greater or less complication. The great backslopes of the tilted mountain blocks, instead of being continuous stratum-planes, are found to be faulted at frequent intervals; and the dips of the rocks change within very short distances.

Rocky Mountain type of structure.—The compressive type of mountain structure finds expression in the Estancia Plains region only in the extreme northeastern part, where the Rocky Mountains end by plunging downward beneath the plains surface. Only a single southward-pitching arch is represented within the limits of the district under consideration. Farther to the eastward the details of structure are more complete. The cross-section to the plains of Las Vegas beyond is well worth much more consideration than can be given it here (Fig. 3).

There is abundant evidence of marked compressive action within the plains area here described, the geologic date of which is probably somewhat earlier than that which the southern nose of the Rockies represents. This period of compression was Early Cretacic. While the evidences are very clear within the limits of the Estancia region there are more abundant exemplifications a short distance outside of this area. On the

Chupadera Mesa just south of Estancia there is an unusually good exposure bearing directly upon this fact (Fig. 5). In some other examples the geologic dates of the compressure are not so clearly set off. In the Sierra de los Caballos where a thrust-plane is shown to advantage (Fig. 4), the movement may have been very recent.

Basin-range type of mountain structure.—In marked contradistinction to the type just described the basin ranges are the result of faulting on an enormous scale. The mountain blocks, rising 3,000 to 5,000 feet above the general level of the high plains which itself is 6,000 feet above the sea, appear tilted as ice cakes in a stream.

There are several instructive features relating to the structure of the Desert ranges that are shown better in and about the region under consideration than anywhere else in the Southwest. Recently a new interest has been awakened in the tectonics of the Great Basin by the publication of a number of more or less suggestive articles. The main structural features about which discussion centers appear to be whether the basin ranges are the result of normal faulting and form "block mountains;" or whether the "block" aspect is only apparent, the monoclinal "blocks" originally being, in reality, sharp asymmetric folds in which subsequent erosion has worn off the steeper limb faster than the other.

In the elucidation of the arguments by specific example, it is unfortunate that many of the illustrations selected have not been chosen with greater discernment. It is now well understood that some of the instances noted furnish the most conclusive proofs directly contrary to the purposes for which they were cited. Without entering into details in regard to many of these cited examples from other parts of the Great Basin region it seems pertinent at this time to call attention briefly to certain features displayed in the New Mexican part of the field. These may help to explain similar phenomena in other districts.

As has recently been noted, the geologic sequence in central New Mexico is especially noteworthy on account of the almost complete absence of the Paleozoic rocks and the enormous development of Mesozoic strata. The important member of the sequence above the Azoic metamorphics is the Mid Carbonic limestone which attains a normal thickness of over 2,000 feet.

No evidence has yet been found that would indicate that any of the present mountain blocks were produced by folding. All observations go to show on the other hand that only faulting is involved. To be sure the sedimentaries of some of these mountains are often folded and closely corrugated. Thrust-planes are plainly visible. Numerous other indications point to tremendous compression at some time or other. But the period of this compression has been found to be mainly a very different one from that during which the present mountains were formed. The compressive action was exerted long before the existing mountain blocks began to rear their heads above the vast plains. Chronologically this period of compressive

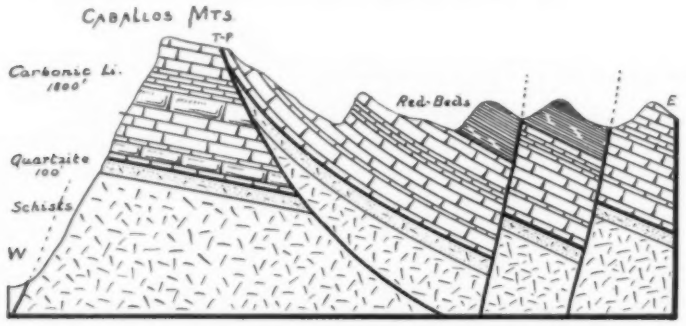


Fig. 4.—Old and modern faulting in Caballos Mountains.

conditions was manifestly subsequent to the Carbonic period because the rocks of this age are involved; but it was before the Late Cretacic period, since Cretacic strata are as clearly not affected.

Certain thrust-planes displayed in the Sierra de los Caballos, to the south of the Estancia region, the geologic sections of which have a bearing upon this point are particularly instructive while the production of others is thought to be somewhat later. Near the highest point of the range, known as Timber Peak, the fault-scarp is over 3,000 feet high and displays an excellent exposure of the rocks throughout this entire vertical distance. The transverse section of the mountain ridge, as shown a short distance to the north, is represented in diagram (Fig. 4). The heavy line, *T–P*, indicates the position of an exceedingly well-displayed thrust-plane. Along

it the beds are very much contorted. The inclination of this thrust-plane is now rather steep, but this is due partly to the fact that the present position of this structure is not the original one. Since the time of its formation the thrust-plane also has been tilted to a marked degree. In point of time the formation of the thrust-plane long antedates the uprising of the present mountain block.

There are in the Sierra de los Caballos at least three distinct periods of faulting. The first was before the formation of the present mountain ridge; the second was coeval with its formation; and the third was long subsequent to its uprising.

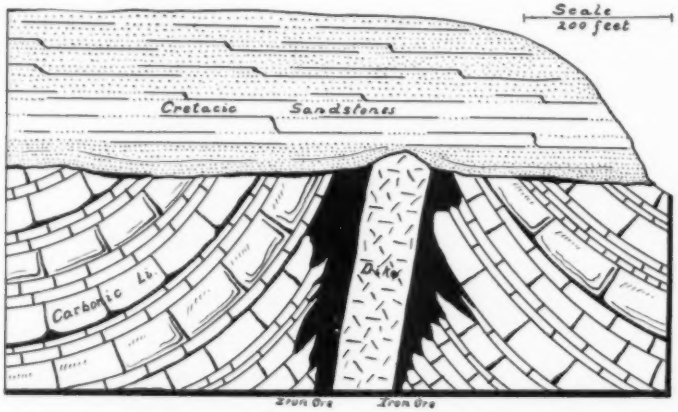


FIG. 5.—Unconformity of Cretaceous on Carboniferous, near Dios Springs.

Were it not for the exceptionally clear evidence to the contrary, casual examination could very easily lead to the conclusion that the Caballos mountain range had been produced by sharp folding, and that the crest of the asymmetric fold had been removed through erosion. The deduction is a natural one especially when in a view from the summit of the range there are plainly shown the strata dipping eastward to form a broad syncline, and coming up again with westerly dips in the great San Andreas block, 30 miles away.

It so happens that in the region under consideration the general sequence of geologic events is sufficiently well known to us to give a good insight into some of the actual conditions that have existed.[1]

[1] *American Journal of Science* (4), Vol. XVIII, pp. 356–58, 1904.

A number of observations lately made emphasizes the great importance of the unconformity at the base of the Cretacic strata of the region. For example, in the Chupadera Mesa in eastern Socorro County, there are found Carbonic limestones highly inclined on either side of huge trachyte dikes, over the whole of which recline nearly horizontally the Cretacic sandstones (Fig. 5). This surface of unconformity represents extensive land erosion. During the interval for which it stands the strata of the region were folded and planed off long before the later Cretacic sediments were laid down.

In nearly all of the basin ranges there are abundant evidences of marked compression producing the phenomena of folding. Yet in every instance personally observed the period of these movements is manifestly long prior to the elevation of the present mountains. The ancient tectonics of the basin ranges is a theme of very great interest.

There is another very deceptive feature connected with the formation of the blocklike mountains of some portions of the Mexican tableland. At the foot of the steeper slope the strata are often found to be tilted at a high angle and inclined away from the range. This attitude of the beds readily suggests at first the possibility of the mountain ridge's being a sharp anticline with the center completely removed through erosion, leaving the limbs of the arch unequally exposed. This condition might be easily fancied because of the fact that the greater part of the height of the mountains, 3,000 to 5,000 feet, is usually composed of massive crystallines and schists, while the crest and the backslope are of limestone.

There are many good reasons for believing that such phenomena as these instead of being ascribable to folding of the asymmetrical type are to be considered merely as an accompaniment of normal faulting. The displacement, however, is on a gigantic scale and under conditions not usually met with. When the hade is not vertical, or nearly so, the strata on the down-throw side to a greater or less degree lag, until a considerable zone is produced in which the beds become highly inclined and in many cases stand even nearly perpendicular. A typical instance is the Sandia Range, east of Albuquerque, as represented below (Fig. 6).

There are strong theoretical grounds for thinking that faulting

instead of folding is to be invoked to explain the structure of the so-called block mountains of the Great Basin region. The principle was clearly set forth by Le Conte[1] as long ago as 1889, when discussing the district between the Sierra Nevada and the Wasatch Mountains. As considered in his textbook[2] the same author has regarded the area in question as a region which was subjected to slow and general uprising but continually adjusted itself through normal faulting in great blocks. By the tilting of these blocks mountain ranges were produced on the elevated edge while on the depressed side were formed valleys which were subsequently filled with sediments. Lauterback[3] is inclined to modify this view

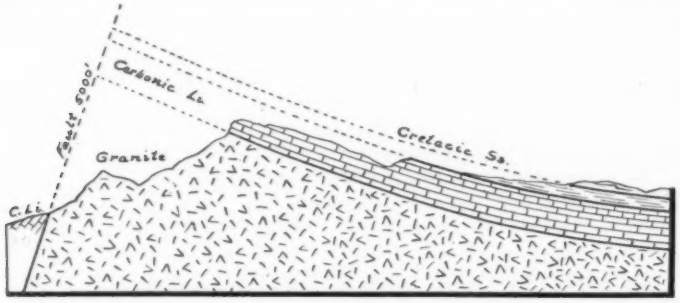


FIG. 6.—Fault-scarp of the Sandia Mountains.

somewhat by regarding the mountain block and the valley block as distinct.

The present relief features of the region are, however, mainly the product of general desert leveling, that is the result of eolian erosian under conditions of an arid climate, and the mountains are to be looked upon as remnantal ranges which are essentially monadnocks.

Laccolithic type of mountain structure.—In the northwestern part of the Estancia Plains there rise four isolated groups of lofty peaks. The several groups are five to six miles from one another and lie in a straight line trending nearly in a northeast and southwest direction. The southernmost group is known as the San Ysidro, or South

[1] *American Journal of Science* (3), Vol. XXXVIII, p. 259, 1889.

[2] *Elements of Geology*, 5th ed., p. 242, 1904.

[3] *Bulletin of the Geological Society of America*, Vol. XV, p. 343, 1904.

Mountains; then comes the Tuertos group; next, the Ortiz, Placer, or Gold mountains; and then, at the north, the Cerillos Hills.

At the present time each of these mountain groups is a huge, many-peaked boss of augitic and hornblendic andesite. Each also rises out of the Cretacic sandstones which are upturned all around. In some places great intrusive sheets extend out from the central mass to a distance of a dozen miles or more; and immense dikes radiate often to twice the distance named.

All evidence goes to show that each of the mountain groups is a laccolith. The molten material, forced upward from beneath, instead of reaching sky floated the overlying strata, forming enormous

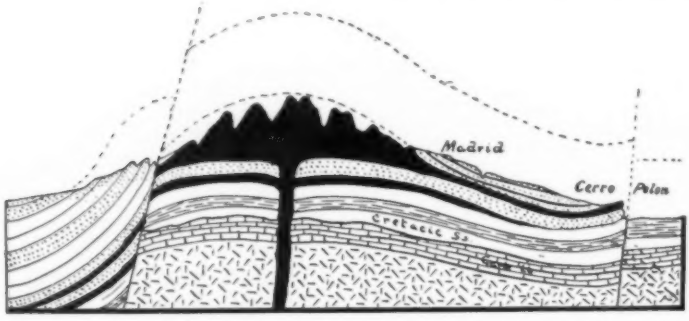


FIG. 7.—Structure of the Ortiz laccolith.

domes, the tops of which were subsequently removed through erosion. A cross-section of the Ortiz group indicates the structure as represented in Fig. 7.

The Ortiz group displays to best advantage the various phenomena of laccolithic nature. The Carbonic limestones have been completely changed by heat into garnet rock, as is well shown at the Lucas mine on the south side of the great dome. Many dikes and several sills have the Ortiz mass as a center. The largest sill extends southeastward to the Cerro Pelon, a distance of about twelve miles. This sill is more than 200 feet thick. The great intrusive sheet is of special interest in the present connection for reason of its penetrating the Cretacic coal measures. There are several important coal seams in close proximity to the intrusive sheet. Where the sill has come

directly into contact with the coal seam the latter has been entirely destroyed. When separated by a few feet of shale a fine grade of anthracite is produced. This variety of coal is extensively mined at the town of Madrid and elsewhere in the vicinity. Seams still farther removed from the sill are bituminous in character; while at a distance of 100 to 200 feet the coal seams are lignitic.

The relations of the sill to the coal seams suggest that the intrusive sheet itself may have followed along a large coal seam, perhaps the most extensive of all, as a horizon along which it was able to move

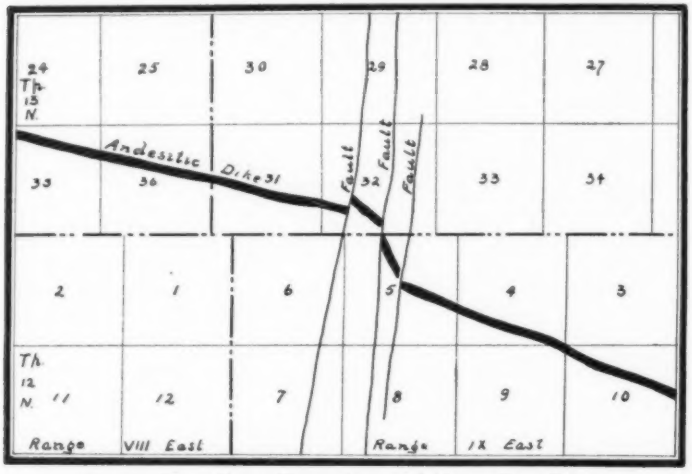


FIG. 8.—Plan of large dike cutting coal-field near Cerro Pelon.

most easily. Similar phenomena have been observed in the Scottish coal fields and in the coal fields of Germany and Hungary.

The dikes originating from the Ortiz mass often extend a score of miles across the plains as huge walls rising 100 to 200 feet above level surface. Some of these dikes show the amount of lateral displacement of the faults. One dike in particular has suffered movement in a remarkable way, as shown in the groundplan (Fig. 8). The squares in the cut are one mile in each direction.

Relations of the structure to the plains surface.—The even surface of the Estancia plains, vast as it is, is not, according to the strict physiographic usage of the term, that of a structural, or stratum-plane,

valley. While in general the rocks are only gently deformed they are locally sharply folded, highly inclined, or even standing on edge. As has been recently shown[1] bolson plains, of which the Estancia Plains are a type, have not the simple substructure that is commonly ascribed to them. They do not appear to be necessarily any newer or later than the plateau plains which overlook them. Their constructional detrital covering is no more important than that of the plateau plains. The wash-deposits brought down from the mountainous periphery are relatively of small importance.

On the other hand, it has been clearly demonstrated in a number of cases that the bedrock surface of the bolson plains, or that plane beneath the detrital covering, is a planation-surface worn out on the

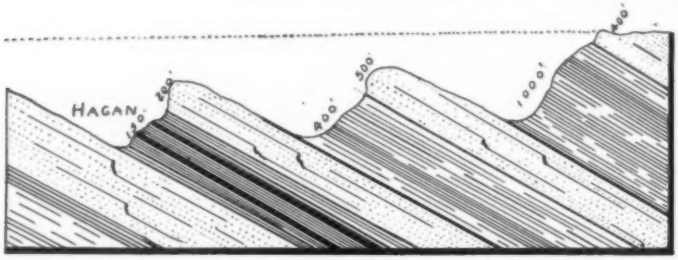


FIG. 9.—Alternation of Cretaceous shales and sandstones at Hagen, thickness about 4,000 feet.

beveled edges of the indurated sedimentaries. This feature is particularly well displayed in the plains between the Ortiz and Sandia mountains. At the Uña de Gato, near Hagan, the structure is as represented below (Fig. 9). The dotted line represents the plains surface; it extends to the right a distance of 20 miles.

The character of this beveling of highly inclined beds, in this case Cretacic sandstones, is admirably shown in the accompanying view near Los Cerrillos, from a photograph taken by Dr. D. W. Johnson. The horizontal beds at the top and above the old planed surface are composed of volcanic breccias, which in turn are overlain by late mesa clays and sands. (See Fig. 12.)

Characteristic rock-masses.—There are represented in the Estancia region five principal kinds of rock-masses. In the great fault-scarp

[1] *American Journal of Science* (4), Vol. XV, p. 207, 1903.

on the west face of the Sandia Mountains there are shown about 4,000 feet of schists, highly metamorphosed clastics, and old intruded granites. These are without much doubt Azoic in age.

Following the fundamental complex are blue limestones of great thickness. They are Mid-Carbonic in age. Above the limestones is normally a remarkable succession of red-beds consisting of shales and shaly sandstones which are doubtless, in great part at least, also of Mid-Carbonic age.

Then comes a prodigious mass of yellow sandstones and shales belonging to the Mid- and Late Cretacic Ages. Finally, are the surface loams, sands and gravels of variable thickness, of Tertiary and Quaternary ages.

Besides the five general classes of rock-masses referred to there is a variety of igneous types.

Geologic formations represented.—The general lithologic character, thickness, and stratigraphic relationships of the various geologic formations which are represented within the limits of the Estancia Plains area need not be described in detail at this time. Two terranal features should, however, be noted: The presence, in this region, of a great succession of "red-beds" fully 1,000 feet in thickness which is not the correlative homologe of the Kansas red-beds; and the remarkable sandstone forming the base of the Cretacic section of the region and to which the term Dakota sandstone has been long applied.

The red-beds of the Sandia side of the Estancia Plains have been termed the Bernalillo shales[1] and they represent the uppermost and third member of the Maderan series.[2] The fact that these "red-beds" are neither of Permian nor of Jura-Trias Age was first made known in 1900 by Herrick[3] who discovered in them a large and characteristic fauna, that clearly connected the section with the so-called Permo-Carboniferous section of central Kansas. The Kansas red-beds or Cimarronian series, and the Triassic red-beds have been shown to be entirely absent in central New Mexico.[4] The title Manzano formation which has been used for the beds in question is inapplicable.

[1] *Ores and Minerals*, Vol. XII, p. 48; also *Report of the Governor of New Mexico to Secretary of the Interior, for 1903*, p. 339, 1903.

[2] This *Journal*, Vol. XIV, p. 152, 1906.

[3] This *Journal*, Vol. VIII, p. 116, 1900.

[4] *American Journal of Science* (4), Vol. XX, p. 423, 1905.

To the eastward of the Estancia Plains there are three important "red-beds" formations, each nearly 1,000 feet thick, and superposed upon one another. They are of widely different geologic ages, and are separated by great erosional unconformities. One is of Mid-Carbonic Age, another of Late Carbonic Age, and the third of Triassic Age. Besides these red-beds there have been long recognized in the region other great red-colored terranes, in the Cretacic section, in the Tertiary section, and in the Devonic section.

At the base of the Cretacic section of this region the Rio Mora sandstone is an important member. It is the so-called Dakota formation of the early geologic reports of the Southwestern United States.

Unconformities.—All of the serial formations of New Mexico, as well as many of their minor members, are separated by marked planes of unconformity. Some of these indicate only notable oscillations of the old shorelines; but several of them are manifestly ancient erosion surfaces. Of the latter class may be mentioned the intervals represented by the sedimentation discordance between the Huronic crystallines and the Manzanan series, between the Cimmaronian and the Maderan, between the former and the Triassic, between the Triassic and the Cretacic, and between the last mentioned and the Cenozoic deposits.

In the interval between the top of the fundamental complex and the Manzanan limestones, there are missing all of the Cambric, the Ordovicic, the Siluric, the Devonic, and the Early Carbonic sequences. These are all very fully represented in the southern part of New Mexico. The interval between the Maderan series and the Cimmaronian shales and sandstones is occupied, a hundred miles south of the Estancia region, by about 3,500 feet of limestones and sandstones, known as the Guadalupan series and regarded as representing the true Permian of Russia. The great sequence of "red-beds," so long of uncertain geologic age, has thus lately been found to be partly of Mid-Carbonic, partly of Late Carbonic, and partly of Triassic Age; the three parts being separated by marked unconformities. A marked erosion unconformity also separates the Triassic shales from the Mid-Cretacic sandstones of the so-called Dakotan series. The missing terranes, represented by the Morrison beds of Jurassic Age and the

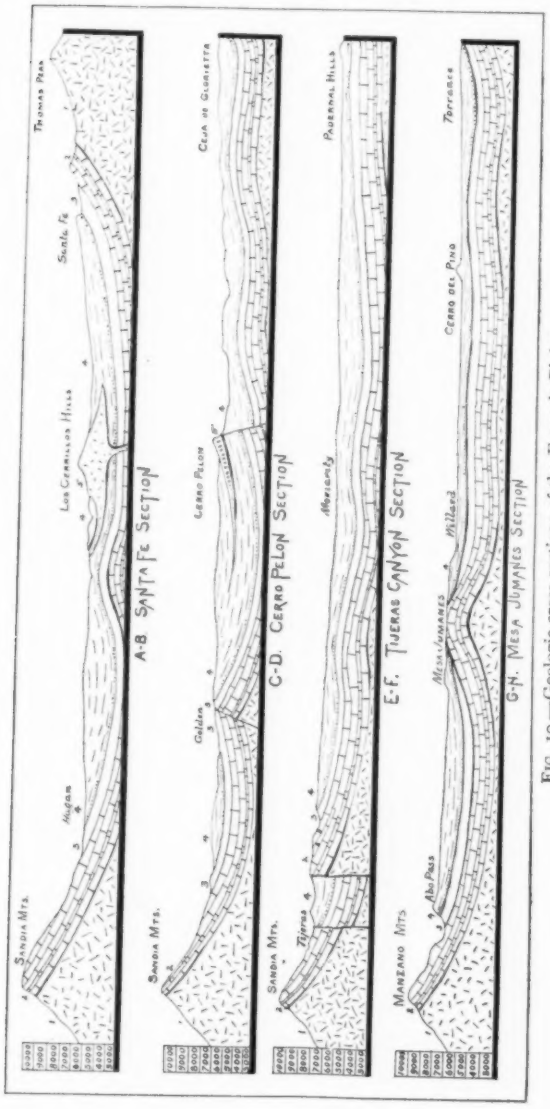


FIG. 10.—Geologic cross-sections of the Estancia Plains.

Comanche beds of Early Cretacic Age are both well displayed farther to the eastward near the Texas line.

General structural features.—The broader tectonic features of the region, as shown in the geologic cross-sections, offer some suggestive considerations regarding the forces which have been at work at the southern extremity of the Rocky Mountains. There are four cross-sections within the limits of the Estancia Plains that are particularly instructive. They may be called the northern section, the Cerro Pelon section, the typical plains section, and the southern section.

The northern, or Santa Fé, geologic cross-section extends from the Thomas Peak of the southern Rockies and a few miles southeast of the city of Santa Fé, in a southwesterly direction, to the Sandia Peak. The distance is 50 miles (section *A–B* of Group, Fig. 10). This section passes through the laccolithic dome of the Cerrillos Hills. In the main, the synclinal character is preserved between the Rocky Mountains and the Sandia Range. The blue Carbonic limestones are well displayed near both ends of the section. In the middle, a little to the south of the line of section, the limestones are also brought to the surface. All of the central part of the trough is occupied by Cretacic formations which are made up chiefly of sandstones.

The Cerro Pelon section trends nearly east and west (section *C–D*). The section is marked by two very pronounced faults which subdivide it into three nearly equal segments. The central portion owes its irregularities largely to the laccolithic disturbances of the neighborhood, the Ortiz group being on one side and the Tuertos group on the other. At the west end the section is monoclinal in character, there being very little if any rising of strata before the first fault is reached. Within this segment a short distance north of the section line several deep-drill wells have been put down.

The middle segment contains the Cerro Pelon, a sharp shoulder which is a feature of the landscape for a distance of many miles around. This hill rises 600 feet above the plain to the east. On its eastern face is a fault-scarp. The prominence of the elevation is due chiefly to the fact that it is capped by a plate of hornblendic andesite which has a thickness of over 400 feet. This capping-plate dips to the westward and is soon covered by the yellow sandstones of the Cre-

tacic Age. The andesitic plate is in reality a great sill, from the Ortiz laccolith, 12 miles to the westward, now bent into a broad syncline.

Some distance beneath the andesitic plate which crowns the Cerro Pelon dark clay-shales are exposed. The valley plain to the eastward is also occupied by soft black shales. At a point several hundred feet below the foot of the Pelon hill a core drill penetrated these shales to a distance of 800 feet without passing through them. They are therefore over 1,000 feet thick.

The dark shales dip to the westward—the valley plain being worn out on their beveled edges. Six miles to the east of the Cerro Pelon the bottom of the shale formation reaches the surface and then the underlying sandstones continue as the surface rocks to the edge of the Glorietta escarpment, forming the western cliff of the Rio Pecos.

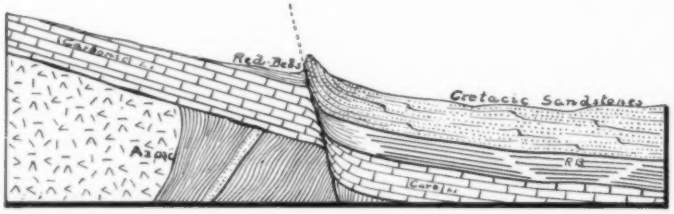


FIG. 11.—Fault bisecting the Sandia and Manzano ranges: displacement about 1,000 feet.

This eastern segment of the section is arching and is the pitching anticline by which the Rocky Mountains are terminated southward.

The Tijeras, or typical plains cross-section extends from the south end of the Sandia Range, at the upper end of the Tijeras Canyon, southeastwardly for a distance of 50 miles to the Padernal Hills, which form the drainage divide between the Estancia Plains and the Valley of the Pecos River (section *E–F* of Group, Fig. 10).

The most characteristic feature of this section is the even surface of the plains worn out on the beveled edges of the strata beneath. Only near the Sandia Range do the strata display any indications of marked dislocation. One of these faults has enabled the Tijeras Canyon to be formed between the Sandia and Manzano ranges. This fault (Fig. 11) has a throw of over 1,000 feet. At the hamlets of Tijeras and San Antonio it is well displayed. At the last-mentioned

FIG. 12.—Tilted Cretaceous sandstones overlain by horizontal volcanic breccia, near Los Cerrillos, height 400 feet.

place the line of movement is marked by a long, high ridge formed of Cretacic sandstones standing on edge.

The southern, or Mesa Jumanes, cross-section passes eastward from the crest of the Manzano Mountains, over the northern extremity of the plateau plain known as the Mesa Jumanes, to beyond the Cerro del Pino near Torrance (section *G–H*, Group, Fig. 10). The western part of the section is synclinal in character with Cretacic beds as the surface rock. The Mesa Jumanes is a tableland with even surface which is elevated 300 feet above the level of the surrounding plains. Its sides are very steep. It appears to have an anticlinal structure, with Carbonic limestones forming the central part. The margins are composed of Cretacic sandstones. The explanation of this remarkable plateau plain appears to be found in the physiography of the region farther to the northeastward. It is believed that the Estancia Plains once formed a part of the Las Vegas plateau which extends northward to the Colorado line, and that the elevated Mesa Jumanes is a remnant of the Ocate plateau so conspicuous to the north of the city of Las Vegas.

THE PHYSICAL ORIGIN OF CERTAIN CONCRETIONS[1]

JAMES H. GARDNER

The literature on the subject of concretions is somewhat limited in extent, and consists largely of descriptive rather than theoretical matter. It is safe to say, however, that distinct types present different problems for solution, and have resulted from divers combinations of chemical and physical laws. The forces brought to play in the forming of one kind may have played no part in the creation of another. Types vary to such a degree that a valid classification is difficult to prepare. Certain writers have made general classifications with reference to manner of growth; for instance, Dana[2] employs the terms "centrifugal" and "centripetal" concretions for growths to and from a center respectively. The latter includes principally concretions of a geodal character. In a similar way the terms "excretions" and "incretions" have been used.[3]

There can be no doubt as to the occurrence of these two general types, but it has been supposed, in many cases, that concretions have originated only through chemical phenomena. There are exceptions, however, in which certain forms of rounded nodules have been considered as resultant forms of physical forces. Kindle[4] accounts for certain concretions of the Chemung by pressure of rising gases of organic origin beneath impervious strata in a semi-plastic state. This idea was suggested by observation of Agassiz and Horsford on "raised hemispherical surfaces" in clayey mud near Cambridge.[5] Kindle makes use of this theory to account for a band of undistorted fossils along the vertical and lower horizontal surfaces of certain of

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] J. D. Dana, *Manual of Geology*, 4th ed., p. 98.

[3] J. E. Todd, "Concretions and Their Geological Effects," *Bulletin of the Geological Society of America*, Vol. XIV, p. 361.

[4] E. M. Kindle, "Concretions in Chemung of Southern New York," *American Geology*, June, 1904.

[5] *American Association for the Advancement of Science*, Vol. IV, p. 12.

the Chemung concretions in southern New York. He supposes that the fossils once occupied a definite horizon and have been pushed upward and around the superjacent material which forms the body of the concretion. Kessler and Hamilton,[1] after giving an analysis of a certain gabbro and contained concretions, conclude with the remark: "This similarity in chemical composition seems to denote that the cause which set about the formation of the spheroids was not a chemical phenomenon." The writers refer to the explanation of Vogelsang[2] in the type locality, Corsica; the latter suggested that this concentric arrangement may be due to irregular areas of cooling and contraction. Blake[3] in referring to the concretionary structure in white volcanic lava of Tucson, Arizona, takes the view that concentric structure, in that case, has been formed by deposition around inclusions through action of permeating ground water.

It is apart from the discussion here, however, to deal with the concretionary and spheroidal structure of many eruptive rocks. The present article is intended to consider the origin of certain types of concretions common to sedimentary deposits only, and especially those concentric nodules of argillaceous composition containing, in many instances, noticeable percentages of calcareous and ferruginous constituents, and to show that possibly physical forces have played no little part in the forming of many of the common spherical, elliptical, discoidal, or irregular concretions in shales or clays. In some cases concretions are known to have originated entirely from chemical solution; an instance of this class is found in the well-known "loess kindchen" of the loess deposits. These calcareous nodules are formed often as incrustated deposits around roots and small plant stems. Other occurrences present equal evidences of purely chemical origin. But many of the more or less rounded nodules of concentric structure and smooth surfaces have merely been alluded to as products of an affinity for like to like with no definite explanation as to how or why they were so formed. The theory of attraction or affinity of like to

[1] H. H. Kessler and W. R. Hamilton, "Orbicular Gabbro of Dehesa Co., California," *American Geology*, Vol. XXXIV, pp. 133–40.

[2] *Sitzungsberichte der niederrheinischen Geschichte*, Vol. XIX, p. 185, 1862.

[3] "Origin of Orbicular and Concentric Structure," *Transactions of the American Institute of Mining Engineers*, Vol. XXXVII, p. 39.

segregate to like, subsequent to deposition of beds, is not sufficient to account for many alluminous concretions in clays and shales. Often the composition of inclosing sediments is closely similar to that of the included concretion but is usually variable.

The writer holds that many such concretions are contemporaneous with the strata in which they are contained; that they have resulted through adhesion of particles in overloaded water volumes disturbed by currents.

During the seasons of 1906 and 1907 the writer observed concretions so formed under natural conditions in alluvial beds of Present Age. This was in the desert region of the San Juan Basin, New Mexico. Conditions were met with here such as are not common to the present land areas. The Rio Chaco, some 40 miles above its confluence with the Rio San Juan, may be taken as a type locality. Here the bed of the stream is made up of alternating layers of sand and alluvial clay. Water flows along the bed only during the winter and spring months or after extensive rains. The fall of the river is very slight. During the flow, vast amounts of sand and clay, or mud, are transported along by the sluggish stream. The water, disappearing rapidly through evaporation and absorption in this arid region, is forced to deposit its sediments along the way; first the heavy sand grains or tiny pebbles, then the finer sand, then the coarse clayey material, and finally the very fine silt, which is held in suspension, becoming more and more concentrated as the water is soaked up or is evaporated. Often this moving mixture is a mere viscid fluid. After the water ceases to run and dries away, a thin coating of clay is left over the surface of the stream bed. Resting in and on this layer are often to be seen great numbers of round, concentric clay concretions. The accompanying plate indicates the manner in which they are collected into aggregations. These concretions are solid but may easily be broken with the hands. Some show nuclei in the form of small pebbles or angular fragments but many of them appear to be of similar material throughout with no recognizable nuclei. Cross-sections revealed that some of them contain small pebbles and sand grains in certain concentric shells of their makeup. The majority average about 1¼ inches in diameter.

The origin of these concretions is not difficult to explain. In

the super-concentrated or overloaded water carrying fine clay particles along a smooth bottom, an adhesion of those particles naturally results. They are pressed together as are finely disseminated particles of butter in the everyday illustration of churning. They may unite with or without a nucleus. A soft nodule will form, grow, and become round by being rotated along its different axes as boys roll snowballs. It will be propelled by the current, gathering as it goes. It will pass over slightly different characters of materials and may gather at intermittent periods; hence different concentric shells will

FIG. 1.—Clay balls in the bed of the Rio Chaco, New Mexico.

result. Should it pass over sandy particles or small pebbles, it will gather them up and may later cover them with additional coatings of clay. At eddies or acute bends in the stream the concretions aggregate and may become slightly welded together. There is a limit to their size depending on the strength of current flowage; they grow until the current is no longer able to transport them, then settle to become covered by subsequent deposition. It may occur that the upper or exposed portion while lying on the bottom receives additional material from the depositing sediments, resulting in an orbital form with a partly inclosing shell which, with modifications,

is a very common occurrence among concretions from sedimentary clay and shale beds. Or it is quite possible that a concretion formed as above may be subjected to stronger currents or clearer water and be eroded to any imaginable shape with smooth outlines. It may be carried to a distance and incorporated in a sediment of an entirely different character from that in which it had its origin. Its composition as a whole would likely in most instances vary from the material immediately surrounding it.

The following are analyses of a typical clay and inclosed concretion from the Champlain clays of the Connecticut Valley.[1]

DARK CLAY LAYER		INCLOSED CONCRETION	
Silica	51.90	Silica	42.93
Iron oxide	8.81	Iron oxide	13.66
Alumina	20.43	Alumina	25.49
Lime	.97	Lime	3.07
Magnesia	1.27	Magnesia	2.09
Manganese oxide	.94	Manganese oxide	1.10
Carbon dioxide	.30	Carbon dioxide	18

It will be observed that the silica and carbon dioxide of the concretion are somewhat lower than that of the clay, while the remaining constituents are higher. While the percentage of lime is 2.10 per cent. greater than in the clay, yet it is not in sufficient amount to justify the term "lime-concretion." The quantity of lime present in this type may vary from a small amount to more than 50 per cent.[2] From the presence of a high percentage of lime it does not follow that this constituent has been the prime factor in the origin of the concretion. Concretions of the character under discussion often show structure made up of very fine material such as would have resulted had they been formed from the adhering of minute particles. Clay and shale concretions have been known to contain gravels, coarse sand grains, or small organic relics as nuclei. Some show small pebbles and coarse sand grains in the form of interior concentric shells.[3] Similar structure has been pointed out as occurring among the concretions which form in the bed of the Rio Chaco.

[1] J. M. A. Sheldon, *The Champlain Clays of the Connecticut Valley.*

[2] C. B. Adams, "Concretions," *Second Annual Report on Geology of the State of Vermont*, pp. 111–18.

[3] "Champlain Clays," *loc. cit.*

Unfortunately the writer has no quantitative analysis of the specimens from the Chaco. They effervesce, however, in the presence of acids. One would expect them to contain a high percentage of soluble materials as is common to ordinary concretions. The last material laid down physically in the water volume is necessarily of a very fine character; furthermore, the water itself, being rapidly concentrated to the point of super-saturation, is forced to throw down its minerals in solution at the same time the concretions are being formed. If the water gains its clayey substances from ferruginous beds, iron oxides will prevail in the last stages of the concentrated solution. If calcareous, then lime will be prevalent in the fine silt at the time when conditions are favorable for the forming of concretions. The same will hold true in the case of other soluble minerals. It is reasonable to suppose that, in accordance with the theory of physical origin, most concretions of this class would be calcareous, since lime is most common. Hence it is seen that while the composition of a concretion so formed depends on chemical relationship, yet the concretionary process is itself a physical one.

Concretions often show flattened or discoid shapes with the greater axes parallel to the bedding planes of the containing strata. Writers have suggested that this is due to there being less resistance to growth in the horizontal than in the vertical planes. In some cases the strata seem to have been pushed away by the enlarging concretion. Such a flattening, however, may have been due entirely to pressure and the strata pushed back around the concretion through resistance to that pressure. There would also be a tendency toward development of cleavage in the concretion at right angles to the pressure and these planes might easily be confused with planes of stratification, the two in normal instances being parallel.

So far as the writer knows, attention was first called by Dr. George P. Merrill[1] to the balling tendency of mud under artificial conditions. He cites the phenomenon of concretionary balls having been formed in mud flowing quietly from the mouth of an iron pipe; the instance was that of pumping sediment from the bottom of the Potomac a few years ago for the purpose of deepening the channel and filling the so-called Potomac flats on the river front at Washington City.

[1] G. P. Merrill, *Rocks, Rock Weathering, and Soils*, p. 37.

Dr. Merrill states that this occurrence shows in an interesting way the manner in which certain concretions are formed.

Another example of the balling tendency of clay particles thickly suspended in current water is shown in the washing of brown iron ores in Alabama.[1] The clay in the log washers often adheres into balls or concretions and it is necessary to remove these by hand before the ore is sent to the furnaces. There may be serious loss of the finer ore particles due to the balls picking them up and carrying them to the waste dump. These mechanical illustrations of the balling tendency of clay are closely similar to those observed to occur under natural conditions in the bed of the Rio Chaco.

Is it not reasonable to suppose that causes which are now effective in producing concretionary structure have been in operation during past ages of the earth's history?[2]

[1] W. B. Phillips, "Iron Making in Alabama," *Alabama Geological Survey.*

[2] Since preparing the above article, the writer has been informed by Mr. Frank L. Hess that mud concretions have been observed by him along the Cuyama River and other localities in California and by Mr. H. S. Gale along a small tributary to White River, near Meeker, Colorado. No doubt the occurrence is familiar to most geologists.

In the Umpqua shales (marine Eocene) of Oregon, Mr. Chester W. Washburne reports having found concretions containing a concentric layer of marine shells; they were in such a position as to indicate that the concretions had been formed by a union of particles due to rolling.

A RECONSTRUCTION OF WATER PLANES OF THE EXTINCT GLACIAL LAKES IN THE LAKE MICHIGAN BASIN[1]

JAMES WALTER GOLDTHWAIT
Dartmouth College

CONTENTS

The Raised Beaches.
Method of Investigation.
The Shore Lines of Lake Chicago.
The Algonquin Beach.
Construction of a Profile of Water Planes.
Significance of the Fan-like Profile.

THE RAISED BEACHES

Around the borders of Lake Michigan are many fragments of abandoned shore lines, which stand at different heights above the present lake. They mark a series of stages of extinct lakes of late glacial times, known as Lake Chicago, Lake Algonquin, and the Nipissing Great Lakes. Near the south end of the lake, where erosion has been slight and the accumulation of shore drift has been going on since the earliest times, there is a record of nearly all the stages through which the lake has passed. On both the east and west sides of the lake, however, in Michigan and Wisconsin, where the cutting back of cliffs at the present level of Lake Michigan has been vigorous, the old shore lines have been partly or wholly destroyed for stretches of five to twenty-five miles. Even where the present lake has not cut away the record, it is usually incomplete, because the higher beaches have been destroyed by cliff recession during the lower of the extinct stages. It follows that the old shore lines preserved at one locality do not necessarily correspond with those at a neighboring locality, either in number or in order. The matter of correlation is not a very simple one; the highest beach at a given locality may not correspond with the highest at a neighboring locality, even though it may be less than a mile away. Moreover, while the

[1] With the permission of the Director of the U. S. Geological Survey.

beaches around the south end of Lake Michigan are still horizontal, having been undisturbed by earth movements since they were formed, those in the more northerly portions have been affected by repeated differential uplifts. Each beach rises northward at a rate different from those above and below it, and at a rate which increases repeatedly in a northward direction. At one or more points, the planes marked by the inclined beaches split, vertically, so that a single stage in the southern part of the lake represents fifteen or twenty stages in the northern part. This is the result of the repeated tiltings of the northern district. The problem of proper correlation of the fragments, then, and of the complete reconstruction of the old water planes is a very difficult one. Not only must as many of these fragments as possible be discovered, but at each locality every beach and terrace of the series must be noted, its strength and peculiar characters recorded, and its altitude measured with all possible precision.

The raised beaches about the south end of Lake Michigan have been described in detail by Leverett,[1] Alden,[2] and others. The beaches along the west side of the lake, in eastern Wisconsin, were first studied in detail by the present writer,[3] in 1905. The planes which were recognized there have since been traced farther north in the upper peninsula of Michigan, by Hobbs.[4] On the east side of the lake, Taylor and Leverett have for several years been accumulating detailed information concerning the beaches. It was with the purpose of supplementing this work by a series of more detailed and precise measurements, and thus establishing more definitely the identity of certain beaches, and their relations, that the writer, under Mr. Taylor's direction, undertook a six weeks' survey of the shore lines along the east side of Lake Michigan in July and August, 1907,

[1] Frank Leverett, "The Illinois Glacial Lobe," *U. S. Geol. Surv.* (Monog. XXXVIII), 1899; also earlier papers (see *op. cit.*, p. 419).

[2] W. C. Alden, "Chicago Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 81, 1902; "The Delavan Lobe of the Lake Michigan Glacier of the Wisconsin Stage of Glaciation, and Associated Phenomena," *U. S. Geol. Surv.* (Prof. Paper 34), 1904; "Milwaukee Special Folio," Geologic Atlas of U. S., *U. S. Geol. Surv.*, Folio 140. 1906.

[3] J. W. Goldthwait, "Correlation of the Raised Beaches on the West Side of Lake Michigan," *Jour. Geol.*, Vol. XIV, pp. 421–24, 1906. "Abandoned Shore-Lines of Eastern Wisconsin," *Wis. Geol. & Nat. Hist. Surv.* (Bull. xvii), 1907.

[4] For the Mich. Geol. Surv. Results not yet published.

for the U. S. Geological Survey. The method of measurement and of assembling the data secured in this study is the same which had been used in eastern Wisconsin in 1905. It was unnecessary in this case, however, to spend much time in exploration; for Mr. Taylor had selected a large number of localities where measurements could be made most advantageously. Considering the shortness of the season, therefore, the field covered was a large one, and the results obtained were unusually complete.

The old water planes, or imaginary surfaces of the extinct lakes, are marked by a variety of shore features. One type which is common on both the past and present shores is the cut bluff and bench. As developed along the present shore of Lake Michigan, the steeply sloping bluff or cliff rises from the water's edge, while the bench or terrace at its base reaches out under water. The point at the base of the bluff or the top of the bench is approximately the highest point at which erosion by storm waves is effective. It is usually a little above the normal lake level. Where bedrock cliffs instead of clay bluffs form the coast, however, the bench is perhaps likely to be a little lower than lake level. There is a constructional variation here of a few feet, but of only a few feet, in the case of Lake Michigan. In making measurements on such a bench, to determine the altitude of the old water plane, the base of the bluff was always taken. It is the only determinable point that one can take as a standard. Care was taken, of course, in making these measurements, to avoid places where the bench had been built up by landslides, or by alluvial wash down the face of the bluff, or where it had been gullied by streams. A range of error of five feet would probably be quite enough in this region to allow for discordances of benches due to original constructional variation in height.

Quite a different feature of topography is the beach or beach ridge —a line of shore drift banked up by the waves at or close to the water's edge, and rising only as high as storm waves can fling material. In exposed places on the shore of Lake Michigan, beaches have been observed whose crests stand fully six feet above calm water level. As a rule, however, they stand only three or four feet above it. In rare cases, where local conditions favor a heavy surf, the beaches probably attain a height of eight or even ten feet. The crest of a

beach, however, is the only point which one can take as a criterion for measuring a water plane; so in the study of these raised beaches it is the crest that has been measured each time. Care was taken to make sure of the presence of gravel on the surface of these beaches, in order to eliminate the effects of wind-blown sand, which often raises a beach, locally. If we allow a range of five feet for original variation in height of beach crests, we have probably satisfied all discordances except those which can be recognized as due to peculiar local conditions.

Other varieties of the beach need scarcely be mentioned, such as the bar or barrier, built between headlands, in comparatively deep water. Its height is liable to be more extreme on that account. The object in the foregoing remarks is to show that the points selected for measurement (the base of a bluff, or the crest of a beach or barrier) were chosen for convenience, not to say from necessity, and that an original constructional variation in height of about five feet is fully recognized.

METHOD OF INVESTIGATION

In the measurements the spirit- or Y-level was used almost exclusively, and to decided advantage. While much has been accomplished with the hand level and aneroid, in skilful hands, neither of these instruments has the accuracy or reliability of the Y-level. The influence of weather conditions, especially lake breezes, on the aneroid, and the personal equation in the hand level are liable to cause mistakes in such work as this. Where there is a whole series of shore lines to be measured in one locality and these beaches and benches follow one another in short vertical intervals, all possible accuracy in measurement is needed to correlate them, individually with members of a similar series at a neighboring locality. The Y-level, then, is almost indispensable for work in the central and southern portions of the Great Lake region, and desirable in all parts of it. Upham and Tyrrell used the Y-level[1] in measurements of altitude of the raised beaches of Lake Agassiz before 1890, Spencer[2] used it in

[1] Warren Upham, "The Glacial Lake Agassiz," *U. S. Geol. Surv.* (Monog., XXV), p. 9, 1896.

[2] J. W. Spencer, "Deformation of the Algonquin Beach and Birth of Lake Huron," *Am. Journ. Sci.* Vol. cxli, pp. 12–21, 1891, and other papers.

Ontario at about the same time. Lawson[1] used it along the north coast of Lake Superior in 1891; but between that time and 1905, the hand level and aneroid were very generally used, instead; and accordingly the correlation and identity of the beaches of the Lake Michigan basin were imperfectly known.

Absolute accuracy is of course impossible even with the Y-level. On the one hand are original variations in height of the beaches and benches, due to local conditions under which they were constructed or cut; for which five feet has been allowed. On the other hand a certain amount of error is involved in the process of leveling; first, through the slight inaccuracy in the use of the instruments, and second, through the use of Lake Michigan as the datum or starting-point. It frequently happened, on days when levels had to be run, that a strong on-shore wind was blowing and the waves were running high, so that one could not tell within half a foot what the normal level of the lake would be at that place. To be quite fair, then, we must expect in these measurements occasional discordances due to a combination of these errors of six feet or so.

THE SHORE LINES OF LAKE CHICAGO

The old shore lines fall into two distinct groups. There is an earlier group, well registered around the south part of Lake Michigan, but unknown in the northern part. These belong to the so-called Lake Chicago, a lake which was confined to the Michigan basin, with its outlet at the extreme southwest corner, into the Desplaines valley at Chicago. A later group, represented by but a single shore line in the southern part of the basin, below the beaches of Lake Chicago, but rising to a considerable height northward, and splitting into a large vertical series, records the complex history of Lake Algonquin and the Nipissing Great Lakes.

The shore lines of Lake Chicago, as distinguished at the south end of the basin, and described by Leverett and Alden, mark three distinct stages, to which the names Glenwood (or 60-foot), Calumet (or 40-foot) and Toleston (or 20-foot) stages have been given. To be more exact, the average altitudes of these three shore lines are 55,

[1] A. C. Lawson, "Sketch of the Coastal Topography of the North Shore of Lake Superior, with Special Reference to the Abandoned Strands of Lake Warren," *Minn. Geol. Surv.*, 20th Ann. Rept. p. 231.

38, and 23 feet above Lake Michigan, or approximately 636, 619, and 604 feet above sea level. In the following table, the altitudes of these beaches is given for six selected localities, where spirit-level measurements have been made by the writer.

Locality	Miles North of Chicago	Glenwood	Calumet	Toleston
Evanston and Niles Center, Ill.	15	636′	619′	605′
Zion City, Ill.	43	634′	621′	x
State Line, Ill., and Wis.	46	634′	616′	x
Line between Racine and Kenosha counties, Wis.	57	637′	621′	...
Holland, Mich.	65	638′	621′	605′
Spring Lake and Eastmanville, Mich.	87	633′	(613′)	602′

It will be noticed that the first four localities are on the west side of Lake Michigan. The last two are on the east side. Spring Lake and Eastmanville are near Grand Haven. The symbol "x" in the table indicates that the shore line is missing because of destructive cliff cutting at a lower stage. Other measurements might be given, less accurate than these, but confirming them, almost without exception. They indicate that as far north as a line through Grand Haven, Mich., and Milwaukee, Wis., the three beaches of Lake Chicago are horizontal. The terrace at Eastmanville, given at 613′ in the table above, is so obscure a feature that its exact altitude cannot be estimated within several feet. Disregarding this one measurement, then, the data show a remarkable accordance in the altitude of beaches, the variation being not more than five feet for each stage. That much variation, as has already been remarked, must be expected in the original construction of the beaches. There is no indication of system in the slight departures from uniformity of height from north to south, hence no reason to suppose that any of these water planes are inclined at all south of Grand Haven and Milwaukee. Apparently, then, these beaches, representing the earliest stages of the lakes of late glacial times have been unaffected by any of the earth movements which are known to have deformed the central and northern portions of the Great Lake region since the ice withdrew.

On the accompanying map (Fig. 1) the northern limit of horizontality for these beaches of Lake Chicago is indicated by a line;

and this line is extended east and southeast through Lake St. Clair and Ashtabula, Ohio, so as to mark the corresponding limit for the beaches of Lakes Maumee and Whittlesey in the Erie basin, as determined by Leverett and Taylor. South of this line, then, there seems to have been no subsequent deformation in either the Michigan or the Erie basins.

Beyond Grand Haven, on the east side of the lake, the data recently collected at several localities, as far north as Ludington,

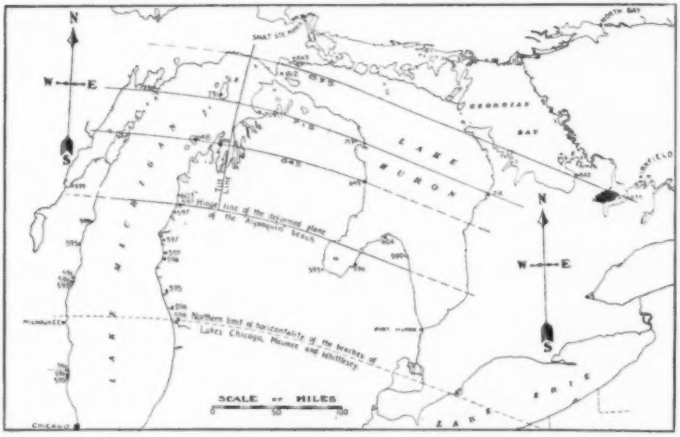


FIG. 1.—Map of Lakes Michigan and Huron, showing northern limit of horizontality of the beaches of Lakes Chicago, Maumee and Whittlesey, altitudes of the Algonquin beach at selected localities, and isobases of deformation and line of maximum inclination of the warped Algonquin water plane.

indicates that the beaches rise northward and increase in number; but the precise correlation has not been possible for several reasons. The measurements are as follows:

Locality	Distinct Beaches at
Muskegon	604′, 609′, 613′–616′, 628′
Montague	632′, 634′, 656′, 658.
Bass Lake	628′–630′, 639′, 642′, 649′–650′.
Ludington and Amber	636′–640′, 673′–675′.

The fragments north of Grand Haven are scarce and generally obscure, becoming sandy and irregular as they go north. It appears as if they were approaching the ice border for those stages, and fading

away among the moraines. Those beaches which locally show strong development cannot be grouped into a single system of diverging planes like the Algonquin beaches presently to be described. The rate of inclination from south to north is hardly one foot per mile. It is possible, then, that the southward slant of these beaches is due wholly to ice attraction, according to the calculations of R. S. Woodward.[1] Assuming an ice sheet of reasonable extent and thickness, Woodward found that its attraction might be sufficient to raise the surface of the lake nearby into a curve, concave upward, with an apparent inclination of several inches to the mile for the first fifty miles or so from the ice border. If this be the right explanation for the Lake Chicago beaches north of Grand Haven, it accounts for the apparent lack of harmony between the measurements; for the relation of successive water planes to each other would be similar to the branchings of a feather (see Fig. 2) and the few points where

FIG. 2.—Diagram showing how a series of ice-attracted water planes might look, in profile.

measurements have been made might happen to lie on several different divergent surfaces. If, on the other hand, the northward ascent of the beaches is due to a series of differential uplifts of the region, these uplifts must have occurred before the formation of the next lower beach, the "Algonquin" beach, for that beach is horizontal over the whole southern half of the Michigan basin.

North of Ludington little is known of these beaches, and no measurements have been made. While the Glenwood and Calumet shore lines might expectedly terminate at any place, against a moraine, the Toleston or lowest shore line of Lake Chicago ought to extend northward to the place where the ice border first uncovered a low pass leading across Michigan into the adjoining Huron basin, probably east of Little Traverse Bay. No traces of such a beach are known. It is probable that the record is too weak and obscure to be recognized.

[1] R. S. Woodward, "On the Form and Position of the Sea Level," *U. S. Geol. Surv.* (Bull. 48. p. 88), 1888.

THE ALGONQUIN BEACH

Below the beaches of Lake Chicago, encircling the south end of Lake Michigan, is the Algonquin beach. It rises northward, in the central and northern part of the basin, as shown by the map, Fig. 1. The identity of this beach, the highest shore line on Mackinac Island, as the "Algonquin" beach[1] of Spencer was long ago recognized by Taylor. On the map, Fig. 1, can be seen the altitude of this Algonquin beach at about thirty-five selected localities in the Huron and Michigan basins. The warped attitude of the water plane which passes through these points is indicated by the system of isobases and the line of maximum inclination which runs perpendicular to them. The data have been taken from several sources. The measurement on the Garden peninsula (725′) is one of many made by Hobbs in 1907. The twenty or more remaining measurements around Lake Michigan and the Straits of Mackinac were made by the present writer, in company with F. B. Taylor, in 1907. On the west side of Lake Huron the measurements were made by Frank Leverett, A. C. Lane, W. M. Gregory, W. F. Cooper, and C. A. Davis. East of Lake Huron the measurements are all Spencer's except the one at Beaverton, which was recently made by Taylor.

Recent investigations by Taylor in Ontario, supplementing earlier studies, indicate that this beach marks a period of activity of *two* outlets, one at Port Huron and one east of Kirkfield, Ontario, where there was an overflow into the valley of the Trent River. This Algonquin beach, of the "two-outlet" stage, seems to be the highest beach common to the Huron and Michigan basins. This gives reason to conclude that when the ice border south of the Straits of Mackinac withdrew so as to let the waters of the Michigan basin merge with those of the Huron basin, the "Trent outlet" was already running. Had the lakes merged before the Trent pass was uncovered and while the Port Huron outlet alone was active, then the plane of that beach, adjusted to the Port Huron outlet, would have been temporarily abandoned when the Trent pass was uncovered, and the waters fell to a low level; and the subsequent uplifts which raised the

[1] J. W. Spencer, "Notes on the Origin and History of the Great Lakes of North America" (abstract), *Am. Assoc. Adv. Sci., Proc.*, Vol. XXXVII, pp. 197–99, 1889, and later papers.

Trent pass up to the level of the one at Port Huron would have raised this old plane (within this region of deformation) well above any subsequent level of the waters. No such plane above the Algonquin beach of the "two-outlet stage" is known, unless it be the Toleston beach. As already noted, this beach is lost, north of Ludington, and no beach is known in the Huron basin which connects with this in the northern part of the lower peninsula of Michigan.

CONSTRUCTION OF A PROFILE OF WATER PLANES

The altitudes of the Algonquin beach at about fifty localities in the northern part of the Michigan basin is shown in Fig. 3. This is a miniature copy of a large scale chart (composed of sheets of the U. S. Lake Survey) on which the data collected in 1905 and 1907 were plotted for final inspection. Through and among these points, a series of isobases was drawn with a vertical interval of ten feet. These were found to be parallel to each other, and to be in harmony with the similar lines across the Huron basin, as shown in Fig. 1. Across the isobases was then drawn a line in the direction of maximum inclination—a gentle curve that changes gradually from N. 15° E. near the Straits of Mackinac to N. 5° E. south of Grand Traverse Bay. With this map as a basis for locating points, a profile of the Algonquin beach and the complex series of shore lines below it was then drawn, as follows: Upon the line of maximum inclination was plotted the position of each station on the east side of the lake where measurements had been made. Each one was then transferred directly to a sheet of co-ordinate paper, on which distances from left to right represented distances from south to north. A horizontal line at the base was taken to represent the present level of Lake Michigan (581.5 feet A. T. in July and August, 1907). With a vertical scale of 20 feet to the inch (500 times as large as the horizontal) the altitude of every beach and bench was recorded by an ordinate. These ordinates served to reconstruct the water plane in profile. A reduced copy of this profile constitutes Plate I. In it, between Hessel and Onekama, a distance of 125 miles, over 25 different lines of levels at as many localities along the east side of Lake Michigan are represented. In other words, the stations are on the average 5 miles apart. About 190 measurements are on well-formed beaches or benches, and

PROFILE
OF THE
WARPED WATER PLANES
OF THE
EXTINCT LAKES ALGONQUIN AND NIPISSING
ON THE EAST SIDE OF LAKE MICHIGAN

The plane of the profile runs in the direction of maximum inclination of the water-planes (N8°E. to N15°E.).
Each ordinate records the altitude of a shore terrace or a beach, as measured (in all but a few cases) by the Y-level.
The vertical lines mark intervals of 5 miles in the direction of maximum inclination.
The vertical exaggeration is 500.

SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10

LEGEND
● Beach Ridge. ▮▮ Observed Variation in Height.
[Cut Bluff. ODB Of Doubtful Identity.
▲ Cut Terrace. ⧗ Ridge on Height of Land.

Onaka
Arcadia
Herring Lake
Beulah

620 ft
600 ft

LAKE LEVEL SUMMER OF 1907 = 581.5 FEET A.T.)

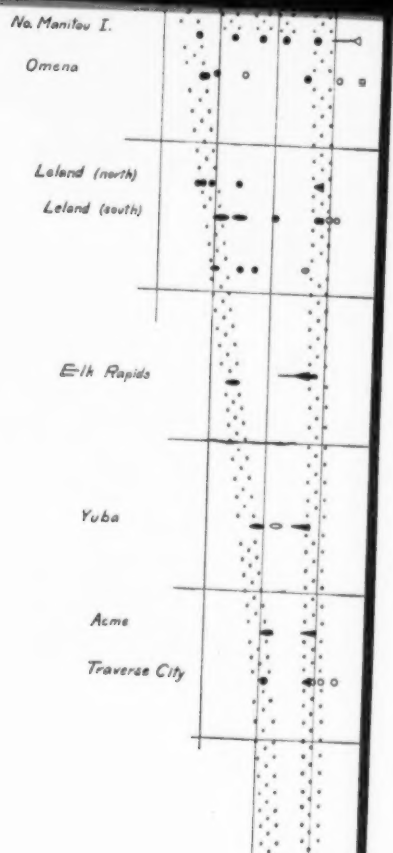
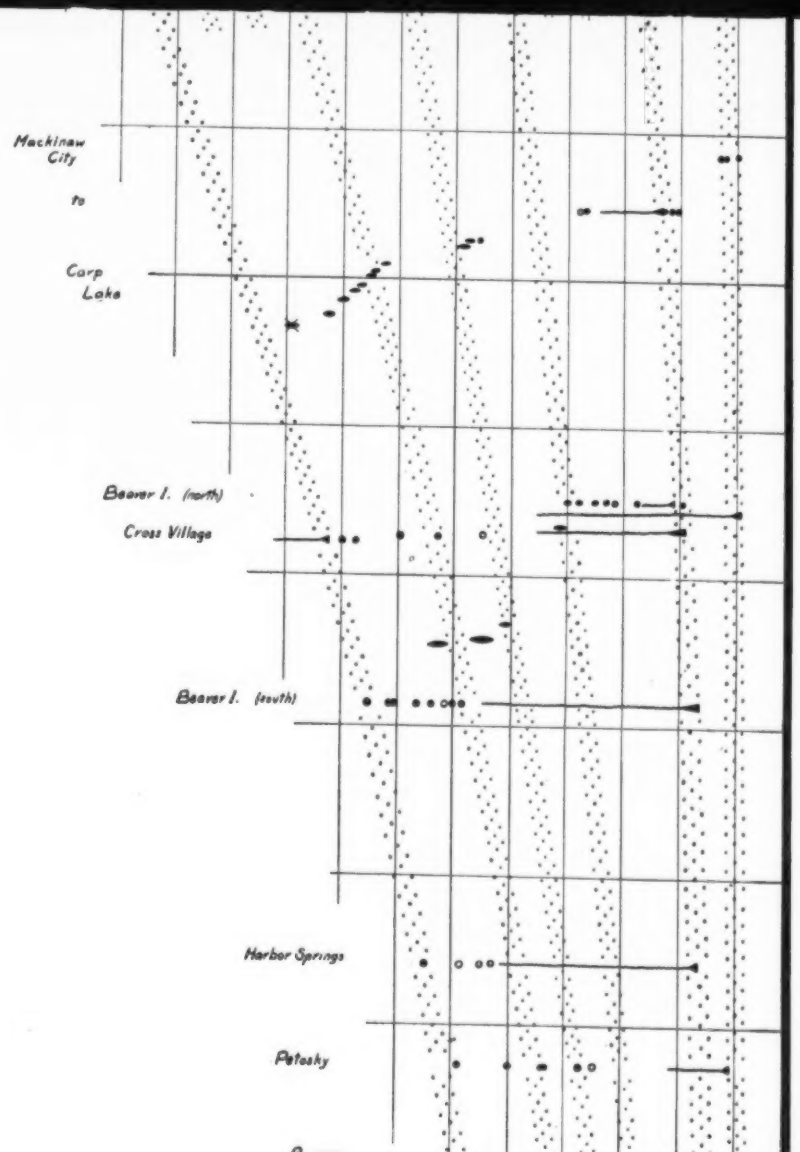
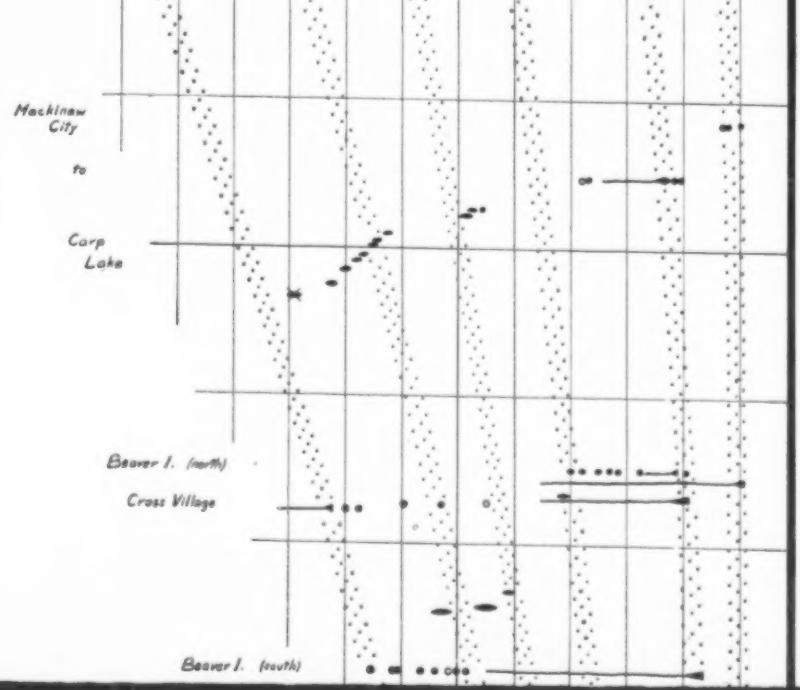

No. Manitou I.
Omena
Leland (north)
Leland (south)
Elk Rapids
Yuba
Acme
Traverse City

PLATE I.—Profile of the warped water planes on the east side of Lake Michigan, nort



north of Onekama.


Mackinaw City
to
Carp Lake
Beaver I. (north)
Cross Village
Beaver I. (south)

Huron
Mackinac I.
St. Ignace
Highest Algonquin Water Plane
Lowest Algonquin Water Plane
Battlefield Water Plane
Highest Fort Brady Water Plane
Nipissing Water Plane
Algoma Water Plane
860
840
820
800
780
760
740
720
700
680
660
640
620
600

about 50 on beaches or benches that are less distinct, though not to be neglected in a fair consideration of evidence. A distinctive symbol is used for the two contrasted types of topography, benches and beaches; and the symbol for a well-formed beach or bench is different from the one for a beach or bench that is faint. The size of the spot is intended to cover the probable range of error in measurement. The height of a cut bluff is shown by a wriggling vertical line.

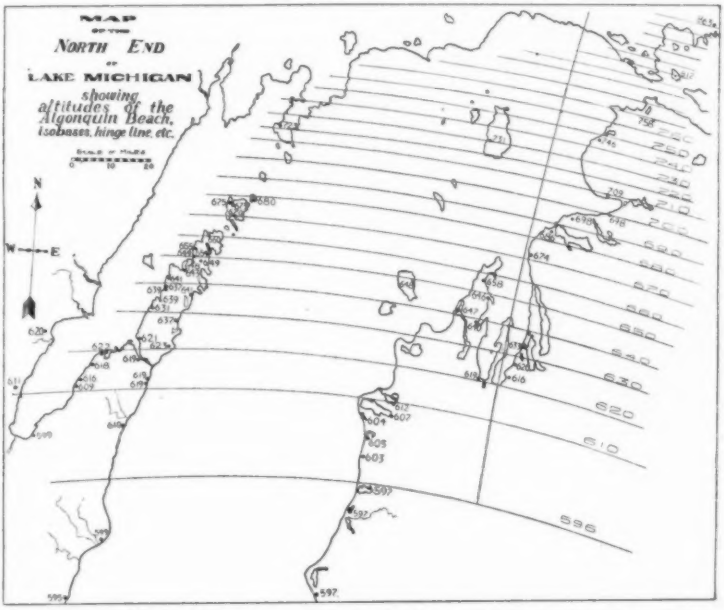


FIG. 3.—Map of the north end of Lake Michigan, showing the warped attitude of the Algonquin water plane.

Through the highest beach thus recorded a line or band was drawn with a thickness (according to the scale) of 6 feet, to represent the range of variation in height to be expected in the original construction of the beach or bench. The line or band, when drawn as a gentle curve, so as to pass most directly through the highest ordinates, includes 21 out of 24 of them. Of the 3 which are either too high or too low, to fall within it, one at Carp Lake, fully 8 feet too low, is

easily accounted for. It is a beach ridge on a height of land, where no opportunity exists for the record of a higher stage. The other two discordant points, one at Petoskey and one at Leland, are five feet below and 4 feet above the center of the band, respectively, instead of being within 3 feet of it. This discordance of one or two feet is not a serious one; for it might be due to an error in leveling which augments an original variation in height, instead of being included in that variation.

The rate of inclination of this Algonquin plane measured from Hessel (at the ancient "Munuscong Islands") southward to Mackinac Island (15 miles) is 3.73 feet per mile. From Mackinac Island to Beaver Island (24 miles) it is 3.30 feet per mile. A rather rapid change of inclination near the isobase of Beaver Island introduces a tilt rate of about 2.00 feet per mile. Over the southern part of Grand Traverse Bay the rate again decreases, perhaps more gradually than in the former case, so that near Traverse City it is about 1.00 foot per mile. The further change from an incline to a horizontal position, which is accomplished near Onekama, seems to be a rather rapid one; for Onekama is only 25 miles south of Traverse City, where, as we have just remarked, the tilt rate is one foot per mile. The abruptness of the changes near Beaver Island and Onekam could be emphasized by representing the plane on the profile by a bent line rather than a curved one. The curve has been used here merely for simplicity, without meaning to imply that the deformation is necessarily a warping rather than an uplift by the tipping or jostling of large fault blocks. Either sort of uplift seems admissable, when due weight is given to the opportunity for variation in the height of the beaches or benches.

Below the highest shore line are a number of others. Some of them are equal to the Algonquin in strength; others are comparatively faint. They can best be recognized in the northern part of the region, where the vertical space between them is greater. On Mackinac Island, for instance, strong benches and beaches record ten lower stages of considerable importance. The Algonquin beach is the highest of a closely spaced group of ridges which are well displayed on the short target range back of Fort Mackinac. This "Algonquin group" of beaches occupies an interval at that place of about 50 feet.

The lowest of them and two intermediate ones are especially prominent. Forty feet below the Algonquins, and separated from them by an interval in which there are no plainly developed beaches or benches, is a beach of remarkable strength, called by Taylor the "Battlefield beach." It was so named because of its conspicuous development as a great ridge of cobblestones and gravel on the old battlefield, on the north slope of the island. Below the Battlefield beach another interval of 40 feet, unoccupied by any very persistent beaches, leads down to the group known as the "Fort Brady beaches." There are several of these ridges. Four of them fill a vertical interval of 25 feet; below them are at least two others of which we have a distinct record. A little below the Fort Brady beaches is the "Nipissing shore line," one of very remarkable strength. It is probably the most conspicuous of all the shore lines, and it is peculiar in consisting usually of a bench and bluff rather than a beach ridge. On Mackinac Island it stands 53 feet above Lake Huron, being represented there, however, by a great deep-water barrier which runs southwest from the Episcopal church. Below the Nipissing is one stage of importance, marked by the "Algoma shore line." At the Straits of Mackinac this stands about 25 feet above the lake.

All these shore lines and groups of shore lines—the Algonquin group, Battlefield beach, Fort Brady beaches, Nipissing shore line, and Algoma shore line—can be traced southward from the Straits of Mackinac, on this profile (Pl. I), with certainty for at least twenty miles, to Beaver Island, where they are all represented. But as they are followed further southward the record of them is found to become more and more imperfect and incomplete. The planes gradually converge until the discrimination between them becomes difficult; and what is more troublesome, in the development of cliffs at the lower stages (especially the Nipissing and the present stage) many of the higher beaches have been cut away and no record of them is left. The exact position of the planes between the Algonquin and the Nipissing, therefore, cannot be absolutely demonstrated, though a reasonable amount of confidence is placed in the reconstruction here given. In the case of the Nipissing shore line, however, there is no uncertainty. Its exceptional strength and peculiar character make it possible to follow this plane southward, down its gentle inclination

of 0.75 feet per mile, diminishing to less than 0.50 feet per mile near Beaver Island, to Onekama, where it becomes horizontal and seems to unite with the Algonquin plane to form the single 596-foot plane already mentioned. While the data for the intermediate planes do not permit an unqualified statement, they seem to indicate that the lowest of the Algonquins, the Battlefield, and the Fort Brady beaches all converge to the same point, Onekama, instead of being overlapped, one after another, by the Nipissing. The Algoma plane seems to constitute another member of this split series; but its exact position south of Petoskey is somewhat in doubt.

It is perhaps possible that the highest Algonquin beach becomes horizontal at about 24 feet above Lake Michigan, near Herring Lake. This is suggested by the work of the present writer in eastern Wisconsin, and by the data thus far collected by those who have worked in the Huron basin. If so, the 14-foot "Nipissing shore line" seems to have very generally destroyed the 24-foot "Algonquin shore line" along the east side of Lake Michigan, south of Herring Lake. The evidence here seems rather to indicate that the Algonquin and Nipissing shore lines coincide to form the single 14-foot shore line. Figures 1, 3, and 5, and Plate I, embody this idea.

SIGNIFICANCE OF THE FAN-LIKE PROFILE

The steepness of inclination of these water planes, and their convergence to a single point, affords a basis for choosing between differential uplifts and ice attraction, to explain their present condition. At the Straits of Mackinac the calculated rate of inclination for the highest Algonquin is 3.73 feet per mile; for the lowest of the Algonquin group, 3.00 feet; for the Battlefield, 2.10 feet; for the highest Fort Brady, 1.29 feet; for the Nipissing, 0.75 feet; and for the Algoma, 0.33 feet. All those above the Nipissing slant too steeply to be accounted for by ice attraction. They must be explained by a series of earth movements which repeatedly raised the shore line of this region out of water. The Nipissing and the Algoma shore lines are inclined no more steeply than the surface of the lake close to the ice border might be inclined by ice attraction; but they are probably inclined more steeply than they could be so far from the ice border for the stages they represent. The ice front must have been at least

200 miles to the northeast of this region; for it had withdrawn from the Mattawa valley, east of North Bay (see Fig. 1), and at this distance its attraction on the waters would hardly have raised the lake surface more than an inch or two to the mile, according to Woodward's computations. Furthermore, the water planes come together at a single point. They should converge in turn to a series of points, feather fashion, if they marked the attraction of the lake to successive positions of the retreating ice front (see Fig. 2). Evidently, then, the inclined position of the planes, and their fan-like relation, must be attributed to earth movements.

The line from which the planes diverge (the "hinge line" on the map, Fig. 1), or as seen on the profile (Plate I) the point at which they split, might be determined, it seems, in either of two ways. It might mark the southern limit of a series of deformations, acting thus as a hinge on which the tiltings took place. If so, it is evident that here were no less than ten or fifteen distinct tilting or warping movements, all of which hinged on the same line. On the other hand, the point of splitting might be located at an outlet (or along the line of equal deformation through an outlet), which together with the region north of it had been raised by tiltings; for as the outlet rose, the horizontal surface of the lake would rise, south of it, drowning the old shore lines there, while to the north the former shore lines would be raised out of water each time and would come to form a fan-like series. This process is illustrated diagrammatically by Fig. 4.

The choice between these two explanations for the case at hand may be quickly made, if one considers the information shown on the map (Fig. 1). There are two outlets, only, which could possibly be associated with the splitting, viz., the Kirkfield and the Port Huron outlets. The isobase through the former (if it were drawn an 875-foot line, parallel to the 835-foot isobase on the map) would pass nowhere near Onekama, but rather through the upper peninsula of Michigan. That is a district as yet not critically examined. The Port Huron pass lies south of the "no tilt" line (or "hinge line" as it is called in Fig. 1); that is, it lies within the district which has been unaffected by uplifts; consequently no fan-like splitting can occur at it or in line with it. It seems necessary to conclude that Onekama lies on the hinge line of the tiltings which raised all the planes into their

inclined positions. That so many tiltings, separated no doubt by considerable intervals of time, should have had the same hinge suggests that this line, for reasons unknown, is one of structural weakness.

In order to show the significance of the fan-like profile of water planes, in Plate I the following series of diagrams (Fig. 5) is introduced. These present in a very conventional and much simplified way the relation which the successive planes of Lake Algonquin and the Nipissing Great Lakes should bear to each other according to the present generally accepted interpretation of the history of the great Lakes, worked out by Mr. Taylor. Since that history is

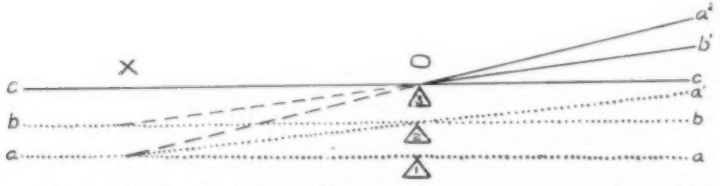


FIG. 4.—Diagram showing in profile how a fan-like group of water planes might be produced by a number of differential uplifts which tilted a lake basin and its outlet. Outlet at *O*. Uplifts affect region to the right of *X*. Three stages are shown. First stage, outlet at *1;* horizontal water plane of the lake at *aa*. Second stage, tilting on right side of *X* has raised outlet to *2;* water plane *aa* has been inclined to aa^1; the lake has risen to plane *bb*, drowning that part of it which lies on left side of outlet. Third stage, another uplift has raised outlet to *3;* has tilted *bb* to bb^1, and increased tilt of aa^1 to aa^2; lake has risen to *cc;* on left side of outlet planes *a* and *b* have been drowned; on right side, they rise, splitting at outlet, fan-fashion.

recognized as subject to revision, through further study, the diagrams should be taken to represent simply the conditions which seem most probable, in the light of the evidence already at hand. Although in the actual case the planes have been warped to curved profiles, as shown in Plate I, they are represented in the diagrams as simply tilted. This is wholly for the sake of simplicity, and must not be thought to imply that the crustal movements were actually tiltings instead of warpings.

The final diagram (6, in Fig. 5) shows the present position of these planes. That portion which lies south of the Trent outlet is based on recent detailed work in the Michigan and Huron basins, including that described in this paper. The large profile, Plate I,

corresponds with that part of Diagram 6. The remaining part, north of the Trent outlet, covers a large field in which studies have been less detailed and the reconstruction on that account cannot be regarded

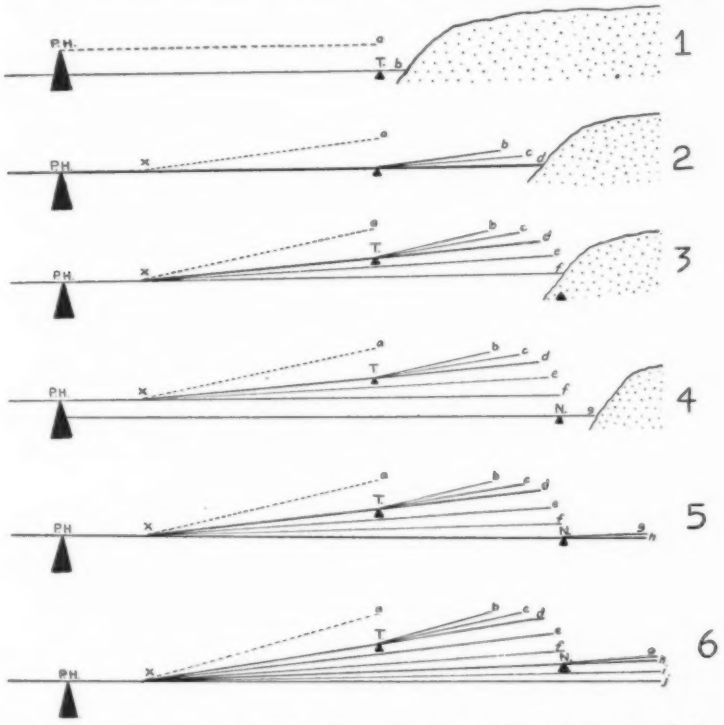


FIG. 5.—Diagrams showing how the water planes of Lake Algonquin and the Nipissing Great Lakes should be related, as seen in profile, if the generally accepted history of the lakes is correct. 1, 2, 3, 4, 5, 6, six selected stages in the lake history during the retreat of the ice border and the differential uplifts. *X*, the point on which the differential uplifts hinged, Onekama. The triangles represent outlets, the controlling point being the apex. *P. H.*, Port Huron outlet. *T*, Trent outlet. *N*, Nipissing outlet. *a*, *b*, *c*, *d*, *e*, etc., successive water planes of the lakes, in the order of their age. *a*, early Algonquin beach, unknown in the Michigan basin, but theoretically necessary in the Huron basin, *b*, *c*, planes of temporary low water stages through the Trent outlet; *d*, plane of the "Algonquin beach;" *e*, plane of the Battlefield beach *f*, plane of a Fort Brady beach; *g*, plane of a temporary low-water stage through the Nipissing pass, possibly marine submergence; *h*, plane of the Nipissing shore line; *i*, plane of the Algoma shore line; *j*, present plane of the Lake Michigan

as actually established. From this series of diagrams it may be seen that (1) the "Algonquin" beach of the Michigan basin marks the "two outlet" stage when the discharge was shared between the pass at Port Huron and that at Kirkfield. Before it there had been a "low-water" stage, adjusted to the Trent (i. e., Kirkfield) outlet in its original low position; but earth movements had lifted the outlet, and consequently the lake level south of it to the level of the Port Huron pass. The records of this low water stage (southern continuations of planes *b* and *c*) have been drowned in the Michigan and Huron basins. The lower members of the group of Lake Algonquin beaches, the Battlefield and Fort Brady beaches, represent successive stages after the restoration of the Port Huron outlet (planes *e* and *f*). Each seems to record a differential uplift in which the northern part of the region was raised out of water, from a hinge near Onekama. The Nipissing plane (*h*) represents, like the Algonquin, a "two-outlet" stage, with the discharge divided between Port Huron and North Bay. Previous to it the low Nipissing pass east of North Bay had been opened and a second low water stage had occurred. The data thus far collected seem to admit a possibility that this was a stage of temporary marine submergence; but further careful studies and more accurate measurements in that most critical field will be needed before the truth is known. With repeated uplifts, the waters of the Huron and Michigan basins rose from this low level, the "low water" beaches were drowned (except north of the Nipissing pass), and the Port Huron outlet was re-established. Since then the Nipissing plane has been raised far out of water. The Algoma beach (*i*) seems to mark the most important pause in this period of comparatively recent uplift.

Reviews

Earthquakes: An Introduction to Seismic Geology. By William Herbert Hobbs. New York: D. Appleton and Co., 1907.

Recent earthquake phenomena in North America have aroused such general interest in the subject that there has arisen a well-defined demand for clearly written books on earthquakes, in which one could find the latest knowledge in such a form as to be intelligible even to the layman. Professor Hobbs has set himself the task of supplying this demand, and has been very successful in his effort. He has given us a book which, though brief, outlines the main facts, theories, and conclusions in a clear, direct, and simple manner. Moreover, he brings the information down to date, which is a matter of great importance in a science that has felt the impulse of new methods that, within a decade, have almost revolutionized certain phases of the subject.

In the first chapter there is a brief summary of early theories for earthquakes, including the simple notions of the ancient philosophers, and a tracing of the steps by which the centrum theory has been gradually abandoned. The next six chapters deal with various topics, among them the cause and distribution of earthquakes, the nature of the shocks, the effect of earthquakes on surface and underground water, and the earthquake faults and fissures and their relation to earth lineaments.

The latter topic, which is the author's special contribution, though touched upon at various points in the book, receives special treatment in chapter vi. The main points in this chapter are already familiar to American geologists from the special articles by Professor Hobbs, and there has been a widespread dissent from his views as to the relation between what he calls earth "lineaments" and seismotectonic lines. To the reviewer it seems that, while Professor Hobbs undoubtedly has a good point here, applied in moderation, he has given it a far greater application than any facts he presents will warrant. There is much reason to believe that many geologists have, in large measure, overlooked the significance of joint planes, faults, and other lines of earth weakness in topographic expression; and the facts presented by Professor Hobbs in this chapter, and in his special articles, clearly show that there is a more definite and wide-spread relation between earth lineaments and seismotectonic lines than has generally been recognized. At the same time, it seems equally clear that Professor Hobbs has read into earth lineaments a relationship to faults and fissures which no facts so far presented will warrant.

To be specific, selecting but one of a number of instances, the city of Elmira, in central southern New York, is, according to Professor Hobbs, one of the greatest centers of intersection of earth lineaments in northeastern United States, no less than five lines centering there. Here, as in other maps, the data upon which

these conclusions are based are almost wholly arbitrary, and totally unconvincing. In some cases it amounts to little more than drawing straight lines connecting two or more places from which one or more earthquakes have been reported. It is to be regretted that so much stress has been placed upon such doubtful cases, for it is liable to discredit the whole theory, by attracting attention to the weak parts and thereby throwing doubts even on the strong parts.

Following these chapters are four in which are presented summary statements of phenomena associated with notable earthquakes in North America and other parts of the world; and this is followed by a chapter on earthquake danger spots within the United States. It is to be hoped that the intimation that the large coastal cities, from Washington to Boston, are on a danger line will not be verified by future earthquake phenomena.

The next chapter deals rather fully with the sounds, or *brontidi*, accompanying earthquakes, and a discussion of the significance of noises from the earth when there are no sensible shocks. Then comes a chapter on the "Study of Earthquakes on the Ground," in which there are some suggestions that will doubtless be of decided value to amateur observers, as well as to others, who have the opportunity of studying an earthquake and its results. The last four chapters deal respectively with disturbances in the ocean, seismographs, interpretation of seismograph records, and disturbances of gravity and earth magnetism. In the last two chapters the importance of distant seismographic records is clearly shown, and the main results so far attained are stated.

Each of the chapters is closed with a selected series of references to original papers, which will be of use to those who wish to pursue the subject further. The book is well printed and adequately illustrated with one hundred and twelve figures and maps, and twenty-four pages of half tone plates, on most of which there are two pictures.

To prepare a general summary of a large subject, in the compass of a little over three hundred pages, and to present the matter clearly and scientifically, and yet in such a manner as to interest both the lay reader and the student of science, is one of the most difficult forms of writing, and the author of this book is to be congratulated on the success which he has attained in his effort to accomplish this end. He has given us a readable book, and yet one in which even the geologist will find new matter, unless he has followed all the latest literature on the subject of earthquakes from the standpoint of both the physicist and the geologist. The student of geology, as well as the layman, will find the book interesting, suggestive, and informing. It takes rank with the best of the general books on seismology.

RALPH S. TARR

The Iron Ores of the Salisbury District of Connecticut, New York, and Massachusetts. By WILLIAM HERBERT HOBBS. (Reprint from *Economic Geology*, Vol. II, No. 2, March-April, 1907, pp. 153–81.)

From the low-grade limonite ore of this district a superior grade of

manganese iron, especially well adapted for car-wheels, has long been prepared by the old charcoal process. Iron has been mined almost continuously since 1734. Most of the mines are located at or near the boundary of the areas of Hudson schist with those of the Stockbridge dolomite, both of which are Cambro-Ordovician sedimentaries. The more important of the exploited ore beds form a nearly continuous series encircling the base of Mt. Washington. The author believes that the ore was derived from pyrite in the Berkshire schists of the adjacent elevated territory, and that the ore bodies have been formed by the replacement of Berkshire schist and Stockbridge dolomite.

C. W. W.

Lead and Zinc Deposits of Virginia. By THOMAS LEONARD WATSON. (Geological Survey of Virginia, Geological Series, Bulletin No. 1. Pp. 156, 14 plates. Published by the Board of Agriculture and Immigration, Richmond, Va., 1905.)

Galenite and sphalerite are associated in all the mining districts, generally as replacement deposits in limestone breccia near faults, and on anticlinal axes. The sulphide ores show no secondary enrichment. The most interesting feature of this region is the secondary oxidized ore which occurs in depressions of the weathered surface of the limestone beneath several feet of residual clay. This ore consists of predominant calamine, associated with smithsonite, and cerrusite, and toward the bottom there is generally some galenite. Commercial ores are limited to the Shenandoah Limestone.

C. W. W.

The Paragenesis of the Minerals in the Glaucophane-Bearing Rocks of California. By JAMES PERRIN SMITH. (Proceedings of the American Philosophical Society, Vol. XLV, 1906, pp. 183–242.)

This paper, and the one by H. S. Washington published last year, make a nearly complete study of the glaucophane schists and related rocks. Professor Smith shows that the glaucophane rocks of the Coast Ranges have been derived from siliceous fragmental sediments, deposits of organic silica, acid arkoses, medium-basic clay shales, basic tuffs, syenites, diorites, diabases, gabbros, and probably pyroxenites. The origin may be determined by study of the chemical composition. Metamorphism has consisted merely in recrystallization, no material has been added or taken away, except that the water which once existed in the pore spaces has been included as water of crystallization. The paper includes thirty-two chemical analyses, and petrographic descriptions of the minerals and rocks.

C. W. W.

The Charleston Earthquake of 1886 in a New Light. By WILLIAM HERBERT HOBBS. (Reprint from *Geological Magazine*, N. S., Decade V, Vol. IV, May, 1907, pp. 197–202.)

The linear distribution of craterlets and of points of special damage to railroad tracks, as determined by Dutton, leads the author to the conclusion that these phenomena indicate the position of faults in the rocks below the coastal series. There are two main sets of faults, one treading about N. 65° E., the other about N. 10° W.

C. W. W.

Some Topographic Features Formed at the Time of Earthquakes and the Origin of Mounds in the Gulf Plain. By WM. H. HOBBS. (Reprint from *American Journal of Science*, Vol. XXIII, pp. 245–56, April, 1907.)

In areas of subsidence, especially during earthquakes, water is squeezed upward through fissures and gives rise to forms such as the mud cones and craterlets in the deltas of great rivers, to the sandstone dikes and pipes observed in many rocks, and to mounds of the "spindle-top" type observed in the Texas and the Baku oil-fields.

C. W. W.

Itinéraires dans le Haut Atlas Marocain. By LOUIS GENTIL. La Géographie, Bulletin de la Société de Géographie, 15 mars, 1908, pp. 177–200. map.

M. Gentil has furnished us a sketch of the topographic and geologic observations made during his journeys in a difficult and dangerous area which includes Cape R'ir and Marrakech in Morocco. Most of the systems of sedimentary rocks are represented in this region, together with volcanic and metamorphic formations of somewhat uncertain age. It is a striking fact that the rocks show in most cases the features which are characteristic of contemporaneous deposits in the greater part of the surface of the earth. Thus the lower Carboniferous contains limestones with numerous crinoids and bryozoans and the Permo-Trias consists of red-beds with gypsum and salt and of other deposits formed on land or in shallow lagoons. As elsewhere, the Cretaceous marks a period of extensive sea transgression and may easily be separated into a lower and an upper division. The shelly sandstones of the Tertiary occupy a tract along the Atlantic coast. The author concludes with a summary of the general orography of the northwestern corner of Africa. His observations confirm the conclusion of Suess, that there is essential continuity between the structures of northern Africa and southern Spain.

H. H.

Lehrbuch der geologischen Formationskunde. By DR. EMMANUEL KAYSER. Dritte Auflage, 1908. Stuttgart: Verlag von Ferdinand Enke.

The third edition of this very useful textbook contains many changes of a minor character which were rendered necessary by the recent rapid strides in statigraphical research. A few sections have been extensively revised and rewritten. The volume is one-sixth larger than the second edition, and contains over 100 additional illustrations of fossils, besides new figures and plates. H. H.

Physical Geography of the Evanston-Waukegan Region. By W. W. ATWOOD AND J. W. GOLDTHWAIT. Urbana, Ill.: Illinois State Geological Survey, Bulletin No. 7, 1908.

This forms the first of a series of "Educational Bulletins" descriptive of various parts of Illinois, and should be of particular interest to teachers of physiography and geology. Excellent accounts of the work and deposits of continental glaciers and of the evolution of lake shore-lines are given, as well as summaries of the history of the greater Great Lakes and of the features characteristic of the various stages of an erosion cycle.

H. H.

The Evolution of the Falls of Niagara. By J. W. SPENCER. 470 pp., 43 pls., 30 figs. Ottawa: Canadian Geological Survey, 1907.

From 1842 to 1905 the average recession of the Canadian Falls was found to be 4.2 ft. per year, and of the American Falls only 0.6 foot per year. G. K. Gilbert (U. S. G. S., Bull. 306) calculated the retreat for the two falls at 5 ft. and 3 in. respectively. The former breadth of the Canadian Falls has been reduced nearly one-seventh by commercial operations, and if the whole amount of water granted by the present franchises for power purposes be utilized these falls will shrink from 3,000 ft. to 1,600 ft., while on the American side there will remain but a few disconnected streams. New soundings show a depth of 92 ft. below the level of Lake Ontario at the head of the Whirlpool Rapids and furnish equally interesting figures for other parts of the river. Much new light is thrown on the history of the Whirlpool—St. David buried channel, and the truth about this feature seems finally to have been made clear. The ancient stream which flowed in it never drained the Erie basin, nor does it account for much of the gorge above the Whirlpool, as has been sometimes stated. To its great depth, however, it caused the formation of the Whirlpool. A small, superficial,

post-Glacial valley diverted the old Niagara above the Whirlpool and concentrated the flow in such a manner that a deep, narrow gorge was excavated. Afterward this was partially filled with blocks of stone and the present Whirlpool Rapids were formed. The basin at the site of the present falls is part of the shallow valley of a former tributary of an old outlet of the Erie basin. The Upper Rapids owe their existence to the fact that the falls, in working back, are climbing the bank of this refilled channel. Below the Whirlpool the well-known Foster Flats indicate the position of the floors of the Niagara River at the time when there were two falls, one in advance of the other. A third cataract existed still farther down the gorge and persisted long after the other two had become united. When the falls had retreated just beyond Foster Flats the drainage from the three upper Great Lakes was added to that of the Erie basin, which had already found an outlet through the Niagara. A study of the fluctuations of the lake levels shows that the tilting of the Great Lakes area has not operated during the last 50 years. The above are only a few of the features connected with Niagara and its history which are discussed in this very complete study of the river. Mr. Spencer places the age of the falls at 39,000 years. H. H.

Transvaal Mines Department. Report of the Geological Survey for the Year 1906. Pretoria, 1907. 140 pp., 37 pl.

The plan of the Transvaal Survey is to publish separate sheet maps of definite portions of the Colony, together with descriptions of the geology of these areas. The report for 1906 contains descriptions of the structure, topography, and stratigraphy of nearly 5,000 square miles of territory and pays especial attention to deposits of economic value. Occurrences of magnesite, coal, magnetite, hematite, antimony, and gold are cited. In connection with the non-detrital auriferous deposits in the Lyndenburg and Carolina districts it is of interest to note that they are of the bedded ore-sheet type: water with gold in solution traveled along bedding planes until the precious metal was precipitated by ferrous compounds. Many of the illustrations in this volume will be appreciated by those who delight in grandly wild scenery. H. H.

Maryland Geological Survey. Vol. VI. 572 pp., 51 pls., 19 figs., map. Baltimore, 1906.

Part I of this report contains a complete summary of the physical features of Maryland, describing the physiography, geology, mineral resources, soils, climate, hydrography, terrestrial magnetism, and forestry of the

state, together with six plates illustrating characteristic fossils of the various formations. A new and well-executed geological and soil map of the state is also included. Part II gives an account of the exhibits made by the Survey at recent expositions. The remaining half of the volume comprises reports on highways and highway construction, and an historical account of the counties and election districts. H. H.

Congrès géologique international. Compte rendu de la dixième session, Mexico, 1906. Imprenta y fototipia de la Secretaria de Fomento, Mexico, 1907.

The report of this session is in two large volumes, containing 1,350 pages and 52 plates. Besides the lists of members, minutes of the meetings, accounts of the excursions taken, etc., 46 papers communicated to the Congress are printed in full. The chief topics discussed are those relating to earthquake and volcanic phenomena and to geological climates. Those relating to the latter subject are: "Interglacial Periods in Canada," by A. P. Coleman; "Glaciation in Lower Cambrian Time" and "Conditions of Climate at Different Geological Epochs," by T. W. E. David; "Ueber die Klima-Aenderungen der geologischen Vergangenheit," by F. Frech; "Climatic Variations," by J. W. Gregory; "The Causes of the Glacial Epoch," by E. W. Hilgard; "Le climate de l'Afrique du Nord pendant le Pliocène supérieur et le Pleistocène," by L. de Lamothe; and "Climats des temps géologiques," by M. Manson. Among the papers on ore deposits may be mentioned: "Ore Deposits at the Contacts of Intrusive Rocks and Limestones," by J. F. Kemp; "The Relation of Ore-Deposition to Physical Conditions," by W. Lindgren; and "Some Relations of Paleogeography to Ore Deposition," by H. F. Bain. H. H.

Water Resources of the East St. Louis District. By ISAIAH BOWMAN AND CHESTER A. REEDS. Illinois State Geological Survey, Bulletin No. 5. Urbana, 1907.

This publication of the young and vigorous Illinois Geological Survey will prove of great value to the numerous manufacturing interests of a district which, though in close proximity to the Mississippi River, has always found the problem of an adequate water supply a difficult one.

H. H.

—American Ceramic Society. Report of the Committee on Co-operation with Federal and State Geological Surveys. [Transactions of American Ceramic Society, Vol. IX.]

—ANDERSON, ROBERT. The Great Japanese Volcano, Aso. [From The Popular Science Monthly, Vol. LXXI, July, 1907.]

—ARNOLD, RALPH, AND ANDERSON, ROBERT. Preliminary Report on the Santa Maria Oil District, Santa Barbara County, California. [U. S. Geological Survey, Bulletin No. 317. Washington, 1907.]

—BALL, LIONEL C. Report on the Norton Goldfield. [Queensland Geological Survey, Publication No. 208. Brisbane, 1906.]

—BARROWS, H. K. Surface Water Supply of New England, 1906. [U. S. Geological Survey, Water Supply Paper No. 201. Washington, 1907.]

———Water Resources of the Kennebec River Basin, Maine. With a section on the Quality of Kennebec River Water by Geo. C. Whipple. [U. S. Geological Survey, Water Supply Paper No. 198. Washington, 1907.]

—BARROWS, H. K., AND GROVER, N. C. Surface Water Supply of Hudson, Passaic, Raritan, and Delaware River Drainages, 1906. [U. S. Geological Survey, Water Supply Paper No. 202. Washington, 1907.]

—BARROWS, H. K., AND HORTON, A. H. Surface Water Supply of Great Lakes and St. Lawrence River Drainages, 1906. [U. S. Geological Survey, Water Supply Paper No. 206. Washington, 1907.]

—BOWMAN, ISAIAH, AND REEDS, CHESTER ALBERT. Water Resources of the East St. Louis District. [Illinois State Geological Survey, Bulletin No. 5, 1907.]

—BROWN, ROBERT MARSHALL. The Movement of Load in Streams of Variable Flow. [From the Bulletin of the American Geographical Society, Vol. XXXIX, March, 1907.]

—CAMERON, FRANK K., AND BELL, JAMES M. The Action of Water and Aqueous Solutions upon Soil Phosphates. [U. S. Department of Agriculture, Bureau of Soils, Bulletin No. 41. Washington, 1907.]

———The Action of Water and Aqueous Solutions upon Soil Carbonates. [U. S. Department of Agriculture, Bureau of Soils, Bulletin No. 49. Washington, 1907.]

—CAMERON, WALTER E. The Annan River Tinfield, Cooktown District. [Queensland Geological Survey, Publication No. 210. Brisbane, 1907.]

———Some Goldfields of the Cape York Peninsula. [Queensland Geological Survey, Publication No. 209. Brisbane, 1907.]

—CARNEY, FRANK. Wave-Cut Terraces in Keuka Valley, Older than the Recession Stage of Wisconsin Ice. [From the American Journal of Science, Vol. XXIII, May, 1907.]

———Valley Dependencies of the Scioto Illinoian Lobe in Licking County, Ohio. [From the Journal of Geology, Vol. XV, No. 5, July–August, 1907.]

———Pre-Wisconsin Drift in the Finger Lake Region of New York. [From the Journal of Geology, Vol. XV, No. 6, September–October, 1907.]

—CAYEUX, M. L. Genèse d'un minerai de fer par decomposition de la glauconie.

———Les fourbes immergées de la côte Bretonne dans la région de Plougasnou-Primel (Finistère). [Extrait du Bulletin de la Société Géologique de France, 4e série, Tome VI, page 142, année 1906.]

———Fixité du niveau de la Méditerranée à l'Epoque historique. [Extrait des Annales de Géographie, Tome XVI, 1907. Paris.]

—CLARKE, JOHN M. Barachois, Bar and Tickle. [From Secondary Education Bulletin 34, Science Teachers Association Proceedings, 1906.]

—COOPER, W. F. Geology and Physical Geography of Michigan. [From Ninth Annual Report of the Michigan Academy of Science.]

—CORSTORPHINE, GEORGE S. The Geological Aspects of South African Scenery. [From The Proceedings of the Geological Society of South Africa, 1907.]

—COSTANZI, GIULIO. Abbozzo di una Carta delle isoanomale della gravita nell, Europa Centrale e nel Giappone Meridionale. [Estratto dalla Rivista Geografica Italiana, Anno XIV, Fascicolo VI–VII, 1907. Firenze.]

—COX, HENRY J. Notes of a Meteorologist in Europe. [From Monthly Weather Review for February, 1907.]

—CURRIE, JAMES. The Mineralogy of the Faeröes, arranged topographically. [Transactions of the Edinburgh Geological Society, Vol. IX, Part I. Edinburgh, 1907.]

—CUSHING, H. P. Geology of the Long Lake Quadrangle. [New York State Museum, Bulletin 115. Albany, 1907.]

—DALE, T. NELSON. The Granites of Maine. With an Introduction by George Otis Smith. [U. S. Geological Survey, Bulletin No. 313. Washington, 1907.]

—DANEŠ, JIŘI V. Das Erdbeben von San Jacinto am 25. Dezember, 1899. [Aus Mitt. d. k. k. Geogr. Gesellschaft in Wien, 1907. Hefte 6 u. 7.]

—DAVIS, WILLIAM MORRIS. A Day in the Cevennes. [From Appalachia, Vol. XI, No. 2.]

———The Place of Coastal Plains in Systematic Physiography. [From Journal of Geography, Vol. VI, No. 1, January, 1907.]

———Glaciation of the Sawatch Range, Colorado. [Bulletin of the Museum of Comparative Zoölogy, Vol. XLIX. Geological Series, Vol. VIII, No. 1. Cambridge, Mass., December, 1905.]

—DORSEY, CLARENCE W. Reclamation of Alkali Land in Salt Lake Valley, Utah. [U. S. Department of Agriculture, Bureau of Soils, Bulletin No. 43. Washington, 1907.]

———Reclamation of Alkali Soils at Billings, Montana. [U. S. Department of Agriculture, Bureau of Soils, Bulletin No. 44. Washington, 1907.]

—Dunstan, B. Some Croydon Gold Mines. [Queensland Geological Survey, Publication No. 212. Brisbane, 1907.]

———Some Gold Mines in the Burnett District. [Queensland Geological Survey, Publication No. 207. Brisbane, 1907.]

———Stanhills Tinfields, Near Croydon. [Queensland Geological Survey, Publication No. 211. Brisbane, 1907.]

—Emmons, S. F., and Irving, J. D. The Downtown District of Leadville, Colorado. [U. S. Geological Survey, Bulletin No. 320. Washington, 1907.]

—Eve, M. A. On the Amount of Radium Emanation in the Atmosphere Near the Earth's Surface. [Bulletin of the Royal Society of Canada, No. I. Ottawa, 1907.]

—Eve, M. A., and McIntosh, D. The Amount of Radium Present in Typical Rocks in the Immediate Neighborhood of Montreal. [Bulletin of the Royal Society of Canada, No. 1. Ottawa, 1907.]

—Gavelin, Axel. Några iakttagelser rörande istidens sista i trakten NV. om Kvikkjokk. [Geol. Fören. Förhandl., N:o .241, Bd. 28, Häft. 3.]

———Studier öfver de Postglaciala Nivå-och Klimatförändringarna på Norra Delen af det Småländska Höglandet. [Sveriges Geologiska Undersökning, Ser. C, N:o .204. Stockholm, 1907.]

—Gilbert, Humphrey, Sewell, and Soulé. The San Francisco Earthquake and Fire of April 18, 1906. [U. S. Geological Survey, Bulletin No. 324. Washington, 1907.]

—Glangeaud, M. Ph. Liquefaction de l'acide carbonique volcanique en Auvergne, la fontaine emporsonnée de Montpensier. [Notes à l'Academie des Sciences. Paris, 1907.]

———La Chaîne des Puys et la Petite Chaîne des Puys. [Notes à l'Academie des Sciences. Paris, 1907.]

—Goldthwait, James Walter. The Abandoned Shore-Lines of Eastern Wisconsin. [Wisconsin Geological and Natural History Survey, Bulletin No. XVII. Madison, 1907.]

—Gordon, C. H. Mississippian (Lower Carboniferous) Formations in the Rio Grande Valley, New Mexico. [From the American Journal of Science, Vol. XXIV, July, 1907.]

—Graton, L. C. The Production of Copper in 1906. [U. S. Geological Survey. Advance Chapter from Mineral Resources of the United States, 1906. Washington, 1907.]

—Griswold, W. T., and Munn, M. J. Geology of Oil and Gas Fields in Steubenville, Burgettstown, and Claysville Quadrangles, Ohio, West Virginia, and Pennsylvania. [U. S. Geological Survey, Bulletin No. 318. Washington, 1907.]

—Grover, N. C. Surface Water Supply of Middle Atlantic States, 1906. [U. S. Geological Survey, Water Supply Paper No. 203. Washington, 1907.]

—Hall, M. R. Surface Water Supply of Southern Atlantic and Eastern Gulf

States, 1906. [U. S. Geological Survey, Water Supply Paper No. 204. Washington, 1907.]

—HALL, M. R., GROVER, N. C., AND HORTON, A. H. Surface Water Supply of Ohio and Lower Eastern Mississippi River Drainages, 1906. [U. S. Geological Survey, Water Supply Paper No. 205. Washington, 1907.]

—HALL, B. M., AND HALL, M. R. Water Resources of Georgia. [U. S. Geological Survey, Water Supply Paper No. 197. Washington, 1907.]

—HARPER, ROLAND M. Some Hitherto Undescribed Outcrops of Altamaha Grit and Their Vegetation. [From the Torreya, Vol. VI, No. 12, December, 1906.]

—HAUG, ÉMILE. Traité de Géologie. I. Les phénomènes géologiques. [Librairie Armand Colin, Paris, 1907.]

—HENRIKSEN, G. Sundry Geological Problems. [Grondahl and Son, Christiania, 1906.]

—HILGARD, EUGENE W. Biographical Memoir of Joseph Le Conte, 1823–1901. [Read before the National Academy of Sciences, April 18, 1907.]

—HOBBS, WILLIAM HERBERT. Earthquakes, an Introduction to Seismic Geology. [D. Appleton & Co., New York, 1907.]

—HOBBS, W. H., AND LEITH, C. K. The Pre-Cambrian Volcanic and Intrusive Rocks of the Fox River Valley, Wisconsin. [Bulletin of the University of Wisconsin, No. 158. Madison, May, 1907.]

—HOTCHKISS, WILLIAM OTIS. Rural Highways of Wisconsin. [Wisconsin Geological and Natural History Survey, Bulletin No. XVIII. Madison, 1906.]

—HUNTINGTON, ELLSWORTH. Some Characteristics of the Glacial Period in non-Glaciated Regions. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 351–88. New York, October, 1907.]

—HUSSAK, EUGENIO. O Palladio e a Platina no Brazil. [Extr. dos Annaes da Escola de Minas de Ouro Preto, N. 8, 1906.]

—Illinois State Geological Survey. Bulletin No. 4—Year Book for 1906. [Urbana, University of Illinois, 1907.]

—JEFFERSON, MARK. Lateral Erosion on Some Michigan Rivers. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 333–50. New York, 1907.]

———Glacial Erosion in the Northfiord. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 413–26. New York, November, 1907.]

—JOHNSON, DOUGLAS WILSON. Report on the Geological Excursion through New Mexico, Arizona, and Utah, Summer of 1906. [From Technology Quarterly, Vol. XIX, No. 4, December, 1906.]

———Volcanic Necks of the Mount Taylor Region, New Mexico. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 25–30. New York, July, 1907.]

—KÖNIGSBERGER, JOH. Normale und anormale Werte der geothermischen Tiefenstufe. [Aus dem Centralblatt für Mineralogie, Geologie und Paläontologie, No. 22, Jahrg. 1907. Stuttgart.]

—KRAUS, E. H., AND COOK, C. W. Datolite from Westfield, Massachusetts. [From the American Journal of Science, Vol. XXII, July, 1906.]

—KRAUS, E. H., AND SCOTT, I. D. Ueber interessante amerikanische Pyritkrystalle. [Sonderabdruck aus "Zeitschrift fur Krystallographie usw.," Band XLIV, Heft 2. Leipzig, 1907.]

—LISBOA, MIGUEL ARROJADO. The Occurrence of Facetted Pebbles on the Central Plateau of Brazil. [From the American Journal of Science, Vol. XXIII, January, 1907.]

———Occorrencias e Evolução das Theorias Relativas á Genesis dos Seixos Facetados. [Extr. dos Annaes da Escola de Minas de Ouro Preto, N. 8, 1906.]

—LOGAN, WM. N. The Clays of Mississippi. [Mississippi Geological Survey, Bulletin No. 2.]

—MAITLAND, A. GIBB. Recent Advances in the Knowledge of the Geology of Western Australia. Presidential address delivered to the Geological Section of the Australasian Association for the Advancement of Science. [Adelaide, 1907.]

—MANSFIELD, GEORGE R. The Characteristics of Various Types of Conglomerates. [From the Journal of Geology, Vol. XV, No. 6, September–October, 1907.]

—MARR, J. E. An Introduction to Geology. [Cambridge University Press, 1905.]

—Maryland, The Physical Features of Calvart County. [Maryland Geological Survey. Baltimore, 1907.]

———The Physical Features of St. Mary's County. [Maryland Geological Survey. Baltimore, 1907.]

—MANSON, D. The Minerals and Genesis of the Veins and Schlieren Traversing the Aegerine-syenite in the Bowral Quarries. [From the Proceedings of the Linnaean Society of N. S. Wales, 1906. Vol. XXXI, Part VI.]

—MEEKER, R. I., AND STEWART, J. E. Surface Water Supply of Missouri River Drainage, 1906. [U. S. Geological Survey, Water Supply Paper No. 208. Washington, 1907.]

—MILLER, WILLET G. The Larder Lake District. The Grenville-Hastings Unconformity and the Probable Identity in Age of the Grenville Limestone with the Keewatin Iron Formation of the Lake Superior Region. [From the 16th Report of the Bureau of Mines, Part I. Toronto, 1907.]

—New Jersey, Geological Survey of. Annual Report of the State Geologist for the Year 1906. [Trenton, 1907].

—OBALSKI, J. Mining Operations in the Province of Quebec for the Year 1906. [Department of Colonization, Mines, and Fisheries. Quebec, 1907.]

—Ontario, Sixteenth Annual Report of the Bureau of Mines of, 1907. [Toronto, 1907.]

—PURDUE, A. H. On the Origin of Limestone Sink-Holes. [From Science, N. S., Vol. XXVI, No. 656, pp. 120–22, July 26, 1907.]

———Cave-Sandstone Deposits of the Southern Ozarks. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 251–56. New York, June, 1907.]

—REID, JOHN A. How Should Faults be Named and Classified? [From Economic Geology, Vol. II, No. 3, April–May, 1907.]

———The Ore Deposits of Copperopolis, Calaveras Co., California. [From Economic Geology, Vol. II, No. 4, June, 1907.]

—RICHARDSON, G. B. Underground Water in Saupete and Central Sevier Valleys, Utah. [U. S. Geological Survey, Water Supply Paper No. 199. Washington, 1907.]

—SANTOLALLA, FERMIN MÁLAGA. Monographia Minera de la Provincia de Huamachuco. [Boletin del Cuerpo de Ingenieros de Minas del Perú, No. 51. Lima, 1907.]

—SCHROEDER, DR. J. L. C. Tabellen zur microskopishen Bestimmung der Mineralien nach ihrem Brechungsindex. Zweite ungearbeitete und vermehrte Auflage von E. H. M. Beekman. [Wiesbaden, C. W. Kreidel's Verlag, 1906.]

—SCHWARZ, ERNEST H. L. Petrographical Notes on the Older Rocks in the Diamond Mines of Kimberly. [Records of the Albany Museum, Vol. II, No. 1, March 28, 1907.]

—SHEPARD, EDWARD M. Underground Waters of Missouri, Their Geology and Utilization. [U. S. Geological Survey, Water Supply Paper No. 195. Washington, 1907.]

—SIMPSON, E. S., AND GIBSON, C. G. The Distribution and Occurrence of the Baser Metals in Western Australia. [Western Australia Geological Survey, Bulletin No. 30. Perth, 1907.]

—SMITH, BURNETT. A New Species of Athleta and a Note on the Morphology of Athleta Petrosa. [From the Proceedings of The Academy of Natural Sciences of Philadelphia, May, 1907.]

———A Contribution to the Morphology of Pyrula. [From the Proceedings of The Academy of Natural Sciences of Philadelphia, May, 1907.]

—SMITH, WARREN D. Petrography of Some Rocks from Benquet Province, Luzon, P. I. [From the Philippine Journal of Science, Vol. II, No. 4, Section A, August, 1907. Manila, P. I.]

—Smithsonian Institution, Annual Report of the Board of Regents of the. Operations, Expenditures, and Condition of the Institution for the Year Ending June 30, 1906. [Washington, 1907.]

———Miscellaneous Collections. Quarterly Issue, Vol. IV, Part II. [Washington, 1907.]

—South Australia, A Review of Mining Operations in the State of. Year Ending June 30th, 1907. [Bureau of Mines, Adelaide, 1907.]

—STAUFFER, CLINTON R. The Hamilton in Ohio. From the Journal of Geology, Vol. XV, No. 6, September–October, 1907.]

———The Devonian Limestones of Central Ohio and Southern Indiana. [From the Ohio Naturalist, Vol. VII, No. 8, June, 1907.]

—STONE, RALPH W., AND CLAPP, FREDERICK G. Oil and Gas Fields of Greene County, Pa. [U. S. Geological Survey, Bulletin No. 304. Washington, 1907.]

—TARR, RALPH S. Second Expedition to Yakutat Bay, Alaska. [From the Bulletin of the Geographical Society of Philadelphia, January, 1907.]

———Glacial Erosion in Alaska. [From The Popular Science Monthly, Vol. LXX, February, 1907.]

—THOMSON, J. ALLEN. Inclusions in Some Volcanic Rocks. [From the Geological Magazine, N. S., Decade V, Vol. IV, November, 1907.]

—UDDEN, JOHAN AUGUST. Report on a Geological Survey of the Lands Belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande Embayment in Texas. [Augustana Book Concern, Rock Island, Illinois, 1907.]

—WEEKS, F. B. Stratigraphy and Structure of the Uinta Range. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 427–48. New York, November, 1907.]

—WEIDMAN, SAMUEL. The Geology of North Central Wisconsin. [Wisconsin Geological and Natural History Survey, Bulletin No. XVI. Madison, 1907.]

—WELLER, STUART. A Report on the Cretaceous Paleontology of New Jersey, Based upon the Stratigraphic Studies of George N. Knapp. Volume IV of the Paleontological Series. Part I—Text. Part II—Plates. [Geological Survey of New Jersey. Trenton, 1907.]

—WELLS, HORACE L. Biographical Memoir of Samuel Lewis Penfield, 1856–1906. [Read before the National Academy of Sciences, April 18, 1907. Washington, 1907.]

—Western Australia Geological Survey. Miscellaneous Reports, Nos. 1–8. Bulletin No. 26. [Perth, 1907.]

—WICHMANN, C. E. A. On Ore Veins in the Province of Limburg. [Koninklÿke Akademie van Wetenschappen te Amsterdam, Proceedings of June 29, 1907.]

—WILLIS, BAILEY. A Theory of Continental Structure Applied to North America. [Bulletin of the Geological Society of America, Vol. XVIII, pp. 389–412. New York, October, 1907.]

—WILLISTON, SAMUEL W. The Skull of Brachauchenius, with Observations on the Relationships of the Plesiosaurs. [From the Proceedings of the U. S. National Museum, Vol. XXXII, pp. 477–89. Washington, 1907.]

—WINCHELL, ALEXANDER N. The Oxidation of Pyrite. [From Economic Geology, Vol. II, No. 3, April–May, 1907.]

—WRIGHT, FRED EUGENE. The Measurement of the Optic Axial Angle of Minerals in the Thin Section. [From The American Journal of Science, Vol. XXIV, October, 1907.]